To the Right Honourable Anthony Greenwood, M.P.,
Minister of Housing and Local Government.

Sir,

1. Our first interim report, submitted in October 1965, described the background to the setting up of the Working Party and gave an account of our activities up to that time. We now have the honour to submit our second report.

2. Since our inception in June 1964 we have met as a full Working Party on twenty-three occasions, and have in addition spent several days visiting representative pipe manufacturing works and research establishments in various parts of the country. Our representatives have spent three and a half weeks in the United States of America studying the extent and nature of research being carried out there in connection with the structural design of sewers; current practice in respect of design and construction; and methods of pipe manufacture. Various sub-committees which we appointed have held a total of forty meetings.

3. We are dividing this report into three main sections. The first deals with the structural design of sewers and the second with practical considerations in design and construction. In the third we attempt to take stock of the further information that is needed and how it may best be obtained. Wherever in this report we refer to sewers it is our intention that our comments should cover all underground pipelines used for drainage purposes, including house drains and connections and pipelines serving industrial premises, as well as main public sewers.

4. It is understood that revised editions of Code of Practice No. 5 (Sewerage) and Code of Practice No. 301 (Building Drainage) will shortly be published by the British Standards Institution, and it will be recalled that it was partly as a result of the request from the Code drafting committee that the Working Party was set up (see paragraph 7 of our first interim report). It may be found that the report we are now submitting does not agree in every particular with the revisions of the Codes, if only because the experimental work to which we refer later was not completed when the revised Codes were drafted, but we have no reason to expect that any apparent conflict will be appreciable.

Section A — The structural design of sewers

Existing structural requirements for rigid pipelines and flexible lines of rigid pipes

5. Sewer pipelines have to support the weight of backfill and surface loads transmitted through the soil to the pipes. The Ministry in its Form K29 at present recognises two approaches to the structural design of pipe sewers constructed with rigid pipes.

6. The first approach, the method which has traditionally been employed in this country, is to provide additional protection with in-situ concrete bed and haunch or surround according to certain fixed rules related only to specific circumstances of depth, size or location of the sewers. These rules were set out in our first interim report (paragraph 66).

7. The second approach or rational design method is to calculate the total external load which the pipeline may have to support and to design a pipeline which will provide sufficient supporting strength to bear the load without damage. Form K29 makes no recommendations in respect of the theories on which detailed calculations should be based or of the surface loads for which it might be reasonable to cater. It does suggest that in the absence of complete computations of the total external design loads the values given in the "Simplified Tables of External Loads on Buried Pipelines" published by the Building Research Station as National Building Studies Special Report No. 32 may be used for single pipes in trenches.

Deficiencies in the existing Form K29 requirements

8. In our first interim report we drew attention to the fact that design on the basis of the simplified tables of Special Report No. 32 results, in a significant range of circumstances, in stronger pipes or beddings with higher supporting strengths being used than design in accordance with the traditional K29 rules. This is now illustrated in the diagrams at Appendices B, C and D, which show the limits of size and depth at which standard strength concrete pipes can be used with various beddings in various loading conditions when designed by the two different methods. It will be seen that design on the basis of Special Report No. 32 severely restricts the use of each form of bedding with this class of pipe by comparison with the traditional rules; and in fact severely restricts the use of pipes of this strength with any form of bedding other than

reinforced concrete. Similar restrictions of greater or lesser extent occur with pipes of other materials and strength classes. The difference between the design methods is likely to be reflected in cost of construction.

9. It is clearly illogical that the Ministry should recognise two approaches to sewer design where they give significantly different results. The implication is that design on the basis of Special Report No. 32 may be extravagant and may in some circumstances lead to unnecessarily costly construction, or that the traditional rules may in some circumstances provide a safety margin in structural strength less than is desirable in modern loading conditions.

10. It was largely because of this anomaly that the Working Party was set up and we therefore had two parallel matters to consider; first in what respect, if any, the traditional rules were deficient or wrong; and second whether the theory and design criteria on which Special Report No. 32 was based were rational and valid.

11. The traditional K29 rules were prepared many years ago and were based largely on practical experience of the capability of pipelines as then constructed of carrying the fill and superimposed loads to which they were expected at that time to be subjected.

12. The superimposed loads which sewers have to carry are now far greater than were ever envisaged when the rules were laid down. At the same time advances in manufacturing techniques have resulted in the production of stronger pipes and the availability of pipes of different strength classes, i.e. of different guaranteed minimum crushing strengths.

13. Furthermore, when the rules were prepared sufficient skilled labour was available to make accurate hand trimming of the trench bottom practicable without excessive expenditure. The rules in effect cater for only two methods of construction: the bedding of the pipes on the trimmed bottom or their bedding on and strengthening with concrete.

14. Cost and shortage of skilled labour have resulted in increasing mechanisation of sewer construction and there is considerable difficulty in preparing the natural bottom of the trench by mechanical means to the accuracy required to provide uniform bedding for pipes. Since mechanised construction is now extensively employed, a range of conditions has arisen between those in which satisfactory bedding on the natural trimmed bottom of the trench can be regarded as practicable and economical and those in which concrete strengthening is necessary. To cater for this range of conditions increasing use has been made of granular material for bedding.

15. The decrease, consequent upon modern constructional techniques, in the range of circumstances in which satisfactory bedding on the natural trimmed bottom would be practicable and economical could not be envisaged when the K29 rules were laid down. They made no provision for this change or for the use of granular material. Furthermore, they included no requirements for the strength of pipes to be used and thus made no provision for the different strengths that are now available. The control of concrete quality and strength is now more easily achieved but the rules make no recommendations in respect of the strength of concrete to be used, or of the thickness of surround for large diameter pipes.

16. These are obvious deficiencies and we accept that if the traditional rules are to be retained permanently, they require at least extension to cater for modern conditions.

17. In respect of rational design Special Report No. 32 was intended as a temporary guide until research and experience could provide more information regarding the extent and effect of loads likely to be encountered, and until the detailed rational method of design became better known. For this reason the design criteria suggested in it were intended to be generous and to provide a safety margin in the worst conditions likely to be encountered. The Special Report is a valuable document and has served a useful purpose but it is clear that the theory and criteria on which it was based must be carefully examined if unnecessary expenditure is to be avoided.

Evidence of damage to sewers

18. One of the first steps which it appeared might assist in assessing the structural sufficiency of sewers constructed in accordance with the traditional K29 rules was to examine the record of behaviour of sewers in the ground. We accordingly appointed a sub-committee to investigate the incidence of failure of sewers and if possible to give reasons for such failures.

19. The sub-committee sought information from about thirty local authorities known to have employed closed-circuit television for sewer surveys. The surveys covered a total length of about 30 miles of sewers. About half this length had been the subject of survey to ascertain the general state of the sewers; the remainder because the condition of the sewers was already suspect for one reason or another. The surveys, particularly those in suspect sewers, revealed defects including collapsed or cracked pipes, many defective rigid joints, and in some cases extensive root growth.

20. In press announcements and in our first report we sought information about sewer failures. The Institution of Municipal Engineers gave us valuable assistance by seeking information regarding districts in which failures had occurred. Forty-three local authorities responded to the request and kindly submitted detailed evidence, so far as this was available, regarding failures in their areas. The reported failures consisted principally of collapsed or cracked pipes and defective cement mortar joints. The affected sewers ranged from 6 in. to 54 in. diameter; few of them were believed to have been protected with concrete, although this would have been called for by the traditional K29 rules in almost half the cases. The information was of course confined to the public sewers which were the responsibility of the local authorities and no information was obtained regarding private house or industrial drainage systems.

21. The sub-committee also sought information regarding the condition of the sewers in their areas from the Chief Engineers to eleven New Towns, in which some 1,150 miles of sewers from 6 in. to 72 in. diameter had been constructed in recent years. Few failures were said to have been discovered.

22. Authorities submitting reports were asked to provide any available information regarding the extent to which their sewers were affected by infiltration

or exfiltration. There can be little doubt that in many areas there is considerable infiltration but quantitative information was seldom available.

23. The information obtained by these means by the sub-committee was obviously minimal in the context of the total length of sewers in existence in this country and quite insufficient to reach any valid conclusions regarding the incidence of failures.

24. In order to reach definite conclusions regarding the cause of failure in a particular case the sub-committee needed information regarding such matters as the crushing strength of the pipes that had been used, the method of bedding and protection, ground conditions, traffic loading and the method and standard of construction and supervision. Detailed evidence on these matters was available in respect of very few of the reported cases of failure and of even fewer of the sewers that had been surveyed by television. A typical example of the difficulty of diagnosing cause of failure was a 9 in. diameter sewer about fifty years old, constructed under a private street at depths from 4 to 18 ft. The subsoil was clay, cement mortar joints had been used and the pipes had no concrete bed, haunch or surround. A television survey revealed eight hundred and sixty-six cracked pipes and nine hundred and four defective joints in the 3,600 yds. of sewer. The defects were not related to depth and some of the deepest sections of the sewer were undamaged. Poor workmanship combined with poor bedding are obvious possible contributory causes of failure but it is impossible to define the causes precisely without additional information. In general no definite pattern emerged from the analysis of failures relating them to age, pipe material, depth, type of loading or similar criteria.

25. The sub-committee considered the possibility of our carrying out sewer television surveys to ascertain the extent of failures in selected drainage areas in different parts of the country, and thus augmenting the information available from other sources. Unless substantial expenditure were to be involved such surveys would necessarily be limited and it would be open to question whether general conclusions from them would be valid.

26. In the short-term the sub-committee could see no other means by which they could obtain more information regarding failures. Furthermore, they became convinced that such information was unlikely to provide us with the evidence we were seeking. To be of real use sufficient detailed evidence must be obtained regarding each case to allow a reasonable diagnosis of the cause of failure; and this was rarely available.

27. They advised us that it was not and, at least for many years, would not be possible to reach definite conclusions regarding the incidence of failures of sewers in this country; and that they could only generalise regarding reasons for failures.

28. At our request they gave us their views on this subject based on the limited evidence available. In their opinion

(a) failures in the sense that sewers are not watertight are probably numerous;

(b) the effect of lack of watertightness varies from district to district; it may have negligible effect on the cost of operation in some areas; in others the cost may be substantial, and even such as to justify replacement of the sewer in question irrespective of the possible danger arising from pollution of the subsoil by exfiltration;

(c) lack of watertightness arises both from joints and cracked pipes but defective rigid joints are probably by far the greatest source of trouble;

(d) a few cases of structural failure of pipes and joints due to overload have been reported with pipelines constructed in accordance with the traditional Form K29 requirements but the limited information available does not indicate that there has been widespread overload structural failure of such pipelines;

(e) failures in whatever form they occur are likely to be due in a high proportion of cases to poor workmanship and non-uniform support of the pipes.

29. We concur with the above views and concluded that

(a) the available information was insufficient to allow us to use it as a basis to judge the adequacy of the traditional K29 rules;

(b) it was unlikely that further investigation of failures would within a reasonable period help us in reaching conclusions on this matter;

(c) the information we had received stressed the deficiencies of rigid joints and the paramount importance of high standards of workmanship and supervision during construction.

30. Despite the fact that short-term investigation of past failures has not proved rewarding, we consider that long-term records of failures are desirable and might prove to be of much value to future generations. Sewer design will always have to be kept under review and the more information that is available the easier this task will be. However, to obtain the detailed information that is necessary in each case in order to determine the cause of the failure, the trouble must be reported immediately it is discovered and in many instances it will be desirable for an inspection to be made and the cause discussed on site with the engineer concerned. At present we have no facilities for such work but later in this report (see paragraph 226) we recommend the setting up of a new section at one of the Government research establishments. The long-term recording and investigation of sewer failures could well be carried out by them in parallel with their main task of research, in connection with which the information obtained is likely to be of value.

Rational design of sewers

31. The second approach recognised in Form K29, that of rational design, involves the determination of the total external load which the pipeline may have to support, and the selection of a pipe of suitable strength together with an appropriate form of bedding which will provide sufficient supporting strength to bear the total calculated load without damage. There are therefore two basic requirements for satisfactory and economical design by this method.

32. Firstly a theory, well supported by field-scale experimental evidence, must be available on which to base calculations both of the loads likely to be imposed and of the supporting strength of the pipeline in given conditions.

33. Secondly and of at least equal importance the engineer must be able to predict the conditions likely to apply to the sewer. Adequate theoretical knowledge supported by practical experience should eliminate arbitrary approach in determining the structural behaviour of underground pipelines in specific conditions but the assessment of the conditions which apply in each case will always remain a matter of engineering judgment.

34. The theory for the determination of the loads to be carried and of the supporting strength of pipelines which is recommended in Special Report No. 32 originates from the work of Marston, Spangler and Schlick at Iowa State University (U.S.A.). Almost all the semi-empirical factors used in this design method are also those suggested by these three engineers as a result of their experimental work. It is the rational theory for sewer pipe design most widely used in the world today.

35. The experimental work on which the theory is based was carried out principally between 1909 and 1933, and most of the work on sewers in narrow trenches was carried out in the earliest experiments with the facilities then available.

36. In recent years Wetzorke has carried out experimental work in Germany as a result of which he considers that the Marston theory results in over-estimation of the loads imposed on pipes. His contentions in this respect were referred to in our first interim report (paragraph 83).

37. We could find no record of pipes designed according to the Marston theory being tested to destruction in field conditions, or of any recent work to determine the actual loads imposed on pipes in working conditions using modern pipes and present-day traffic loads and speeds.

Visit to the United States

38. To enable us to judge the need for up-to-date experimental evidence in respect of the theory we considered it desirable to be better informed as to the extent and character of the work which had been done in the United States and on the current thinking there about the need for and scope of further progressive study. We therefore sent representatives to the United States to obtain first-hand information on these and other pertinent matters, including the research and experimental work at present being done there on this subject, and the methods of instrumentation used; constructional practice, with particular reference to mechanisation and the development of plant; the extent to which engineers were in fact adopting rational methods for sewer design; and how such methods were affecting or being affected by the development of more advanced constructional techniques.

39. During the visit discussions took place with representatives of two Government departments, seven local authorities and four consulting engineering firms. Five research establishments and four pipe manufacturing plants were visited. Sewers under construction were inspected at twenty-five sites.

40. Our representatives found no evidence of any major research work on this subject having been undertaken since that of Marston, Spangler and Schlick. They were informed of two limited programmes of research now in progress, each of which might provide some evidence in respect of the theory. Neither included any large-scale field experimental work.

41. We refer later to various matters reported to us by our representatives arising out of the visit. It was interesting to find that rational theoretical design methods appear to have been applied in the United States for many years. However, the proof of the theory by field-scale testing appears to be limited and their engineers still seem to be faced with many of the same problems in applying the theory to practice that we encounter here. Assessment of the efficacy of rational design methods there was difficult because evidence in respect of the behaviour of sewers in the ground and of failures appeared to be as lacking as in this country.

42. We are appreciative of the help which was so readily given to our representatives everywhere they went and we have noted with interest the information they collected. We value the contact established with engineers concerned with many fields of drainage work in the United States and look forward to continued co-operation and exchange of ideas and information with them.

Our pilot programme of experimental work

43. Our early examination of the problem had convinced us that before we could recommend the adoption of the Marston or any other theory we must obtain reliable up-to-date experimental evidence of its efficacy, and that this could only be done by full-scale field experiments. This view was later substantiated by the information obtained by our representatives in the United States.

44. We had decided that our three primary objectives should be to ascertain

(a) the overall safety margin in structural strength of a sewer pipeline laid under practical conditions and subjected to normally occurring loads;

(b) whether the theoretical predictions of the loads imposed on buried pipe sewers were reasonably correct;

(c) whether the theoretical predictions of the supporting strengths of pipes laid on various beddings were reasonably correct.

45. To design a programme of experiments to cover all three objectives was impracticable. We had decided that objectives (a) and (b) should have priority and had planned a first major programme of experimental work accordingly. The principle of the work we had in mind was that sewer pipelines of different diameters would be constructed under a road. Pipes of known strength would be used, laid on various beddings at various depths. Static and transient loads would be imposed on the pipelines and the effect in terms of strain and deformation would be measured and recorded with instruments installed in the pipes for the purpose. The loads would continue to be increased and the strains recorded until failure of the sewers occurred, if this could be achieved.

46. It was clear that the great range of variables in sewer design and construction could not be covered by one programme of experiments. To obtain reliable design data the programme would have to be repeated a number of times in

different ground conditions and with different combinations of the many variables. There would then still remain objective (c) for which an entirely separate but at least equally extensive series of tests would be necessary.

47. We realised that programmes of this nature would be costly and would take some time to complete, but we were and remain convinced that it is only by obtaining evidence from field-scale work of this kind that we shall be able to give adequate well-based guidance on the problems of structural design of sewers.

48. Before offering advice on the research to be undertaken we had to be satisfied that the work we had in mind was practicable and that the many problems which it entailed, particularly in respect of the complex instrumentation required, could be overcome.

49. We decided to use the funds at our disposal to institute a pilot programme of experiments, designed to establish a technique for the major work which must follow.

50. The search for a convenient site for the work led to the Military Engineering Experimental Establishment (MEXE) where there was a 500 ton bridge testing rig. The Director of MEXE kindly agreed to collaborate with us and the work began in July 1965 and was completed by December 1965.

51. We were greatly encouraged in our belief that such work was necessary by the ready and extensive help given to us by those concerned with many sectors of the drainage field. The clay and concrete pipes needed for the experiments were provided free of charge by the Clay Pipe Development Association Ltd. and the Concrete Pipe Association. They were manufactured by the Hepworth Iron Company Ltd. and the Redland Pipe Company Ltd. The latter company also provided facilities for laboratory tests to destruction of concrete pipes and for the calibration of concrete and iron pipes. Stanton and Staveley Ltd. provided cast iron control pipes free of charge. The British Ceramic Research Association were responsible for the installation of instruments in the clay pipes, for laboratory tests to destruction on pipes of this material, and for calibration of clay and iron pipes. MEXE carried out the civil engineering work and the repetitive loading tests on all pipes. The Road Research Laboratory arranged for the provision of the instruments for measuring static and dynamic strains and deflections and were responsible for these measurements. The Building Research Station compared the measured strains and deflections with the values deduced from the available theories. We received valuable advice from many specialists in the field of instrumentation including particularly the staff of the research establishments referred to above.

52. We are grateful for the assistance of all those who contributed to the work, without which it could not have been carried out. Not least are we indebted to five of our own members: Mr. I. H. Hainsworth, who was responsible for overall supervision and co-ordination of the work; Dr. A. C. Whiffin and Mr. O. C. Young, whose technical advice helped to overcome many problems and who arranged for the setting out and analysis of the results; and Mr. J. M. Haseldine and Mr. R. R. Beaumont, who advised us on the constructional work from the point of view of the engineer and the contractor respectively.

53. Instruments to measure strain and deflection were installed in 12 in. diameter clay and 36 in. diameter plain concrete pipes and in cast iron control pipes of the same diameters. Calibration tests were carried out in mechanical testing machines to establish a relationship between load and strain or deflection for each gauge in each pipe. A number of clay and concrete pipes from the same manufacturing batches as those to be used in the experiments were loaded to destruction in the testing machines to determine their ultimate crushing strengths.

54. Trenches of sufficient depth to give 4 ft. of cover to the finished pipelines were excavated beneath the 500 ton bridge testing rig. 12 in. and 36 in. diameter pipelines with mechanical joints, using the calibrated and instrumented test pipes, were laid on granular bedding material of specified grading and the trenches were backfilled. A road designed to have average load-spreading characteristics was constructed over the trenches. In these operations we attempted to avoid an unduly high standard of workmanship and uniformity of compaction of backfilling and to achieve only the average standards which are likely to apply in normal field conditions. Careful note was taken of the characteristics of the soil as excavated and of the degree of compaction of backfilling achieved.

55. The tensile strains induced by jointing the pipes were recorded. Measurements were made of the dynamic strains brought about by backfilling compaction and road construction equipment. Static strains were measured and recorded at various stages of backfilling and road construction and until the repetitive loading tests were well advanced.

56. Surface loading arrangements were designed to simulate the effect of vehicle loads. The loads were applied by means of the bridge testing rig through elliptical rubber pads on the road surface to reproduce tyre effects. The pads were located in accordance with the Type HB road loading wheel and axle layout of B.S.153, on which the loads in Special Report No. 32 are calculated.

57. Before the main series of repetitive surface loading tests was started various positions of the simulated vehicle axle in relation to the pipeline were tried in order to establish which produced the greatest effect on the pipes. By far the greatest strain was induced when this axle was located in line with and directly above the pipe axis and this loading position was used throughout the main series of tests.

58. A load was applied to the pads above the instrumented clay or concrete pipe under test and the strain and deflection induced in the pipe were measured and recorded. The load was removed and re-applied a number of times until the strains and deflections became sensibly constant. The load was increased and the procedure repeated. The process was continued until failure of the pipe occurred.

59. The whole procedure was repeated with each instrumented test pipe and with the iron control pipes, except that of course in the case of the latter the loading could not be taken to the point of failure.

60. At the end of the tests the trenches were re-excavated and the pipes were removed and examined.

61. In the analysis of the static fill results the expected external load imposed on the pipes by the fill under the given conditions was calculated by the application of the Marston theory. Division of this theoretical load by the assumed bedding factor of the granular material converted it into an equivalent load in the testing machine, or the 'theoretical test load equivalent'.

62. Division of the strain recorded for a given gauge in the ground by the appropriate calibration figure for the gauge, obtained from the load/strain curves produced in the testing machine before the pipes were laid, gave the load in the testing machine equivalent to the actual loading in the ground, or the 'experimental test load equivalent'.

63. The relationship between the theoretical test load equivalent and the experimental test load equivalent gave a factor, which we termed the 'discrepancy factor', that expressed the degree of discrepancy between the theoretically predicted and experimentally measured values. Thus a discrepancy factor greater than unity would indicate that theory erred on the side of safety.

64. It must be remembered that the discrepancy factors were calculated on an assumed value of bedding factor. Thus a discrepancy factor greater than unity may mean either that the loads actually transmitted to the pipe were less than those given by theory or that the bedding factor, and thus the supporting strength of the pipeline, was greater than had been assumed. There was no way of determining the relative contributions of these two influences from the experimental data obtained in these limited pilot experiments.

65. The results of the repetitive surface loading tests were analysed in the same way, using current rational design theory for the calculation of theoretical test load equivalents.

66. The results of the fill load experiments indicate that the experimental test load equivalents of the actual loads imposed on the pipes by the backfilling after the road construction was completed were initially substantially less than the test load equivalents predicted by the Marston theory. However, there was a tendency for them to increase with time and it seemed that the application and removal of heavy surface loads resulted in a further increase in fill load. By the time that the repetitive loading tests had been partially carried out, the discrepancy factors for the 36 in. diameter pipes were about 1 and for the 12 in. diameter pipes about 2; that is, the experimental test load equivalents for the 36 in. diameter pipes were about equal to those predicted by theory, whilst those for the 12 in. diameter pipes were about half the theoretical values.

67. In respect of the repetitive surface loading tests the results indicated that current design theory over-estimated the test load equivalents of the surface loads transmitted to the pipes by factors ranging from about 1·5 to 2·2. There was no significant difference in the factors for the 12 in. and 36 in. diameter pipes but there was evidence that a large increase of surface load caused some reduction of these factors.

Impact factor and the Road Research Laboratory tests

68. We referred in paragraph 33 to the second basic requirement of satisfactory and economical rational design, namely the ability of the engineer to

predict the conditions likely to apply to a sewer pipeline. In some circumstances one of the most important of these is the load likely to be imposed on the surface of the ground above the sewer. In this respect Special Report No. 32 suggests that

(a) for sewers to be laid under roads provision should be made for a maximum of eight wheel loads, each of 20,000 lbs. static weight, arranged as in B.S.153 Type HB road loading, acting simultaneously with an impact factor of 2·0, or for a maximum uniformly distributed surcharge load of 500 lbs./sq. ft. of unlimited extent in plan, whichever is calculated to produce the greatest effect on the pipeline in the given conditions;

(b) for sewers to be laid in fields and gardens, private carriageways and access roads provision should be made for a maximum of two wheel loads, each of 7,000 lbs. static weight, spaced 3 ft. apart, acting simultaneously with an impact factor of 2·0, or for a maximum uniformly distributed surcharge load of 500 lbs./sq. ft. of unlimited extent in plan, whichever is calculated to produce the greatest effect on the pipeline in the given conditions.

69. Our representatives found that in the United States, in circumstances in which any provision at all is made for vehicular loading, calculations are based on a maximum of two wheel loads, each of 16,000 lbs. static weight, spaced 3 ft. apart, acting simultaneously with an impact factor of 1·5. No general provision appears to be made for uniformly distributed surcharge loading, except where it is considered that there is a definite likelihood of loads of this nature being imposed on the pipeline.

70. We also found that significantly different impact factors were used in other parts of the world, for example in Australia 1·3 reducing to 1·0 at a depth of 3 ft. and in Germany 1·6 reducing to 1·3 at a depth of 1 metre.

71. The surface loads likely to be imposed above a sewer are matters which must be considered in the light of such criteria as the location of the sewer, legal limitations on maximum vehicle loads, and the likelihood of such loads being imposed in particular circumstances. They may obviously vary from country to country and indeed from site to site.

72. There is no reason apparent, however, why the empirical factor used to allow for the impact effects of moving vehicles should vary substantially in different parts of the world. Impact factor has a significant effect on the design of sewers at depths up to about 10 ft. The factor of 2·0 used in this country is much higher than the figures used in other countries and results in substantially higher calculated superimposed loads than elsewhere. Very little detailed experimental work appeared to have been carried out on this matter and there was little definite evidence in support of any of the figures which had been adopted.

73. As stated in our first interim report we considered research work on this subject to be urgently necessary. The Road Research Laboratory of the Ministry of Transport had intended for some time to carry out experiments on the problem and kindly agreed to bring forward their work on this subject in view of the urgency in relation to our task. We co-operated with them in the preparation of a programme of tests, which the Laboratory carried out at Harmondsworth between November 1964 and April 1966.

74. The experiments were designed to investigate the effect on impact factor of depth of embedment of pipe; size of pipe; type of bedding; type of backfilling; vehicle speed; axle load; and type of vehicle.

75. 18 in. and 36 in. diameter plain concrete pipes for the tests were supplied free of charge by the Concrete Pipe Association and manufactured by the Mono Concrete Company. Instruments to measure strain and deflection were installed in them. Calibration tests were carried out in a mechanical testing machine to establish a relationship between load and strain or deflection for each gauge in each pipe. A number of pipes from the same manufacturing batch as the test pipes were tested to destruction in the testing machine to determine their ultimate crushing strength.

76. A length of the Road Research Laboratory's existing loop road near the Colnbrook bypass was reconstructed using a specification designed to result in average load-spreading characteristics. Trenches were excavated across it and three 18 in. and five 36 in. diameter pipelines with mechanical joints were constructed, each of which included instrumented and calibrated test pipes. The pipelines were laid with various depths of cover and different lines were bedded on different materials including granular bedding of specified grading, plain concrete and reinforced concrete.

77. Some of the trenches were backfilled with the gravelly-clay excavated from them; others were backfilled with material imported to the site, including sandy clay, loosely compacted in one case and well compacted in another; clay of high liquid limit; granular material; and lean-mix concrete. The road surface was reinstated over some of the trenches; in others the backfilling material was carried up to the surface level.

78. A vehicle of known weight was run at measured speed over a selected trench and the additional strain and deflection induced in the test pipes were measured and recorded. A plank 1¾ ins. thick was placed in the position relative to the trench found by trial to produce the greatest impact effect on the pipeline. The same vehicle was run over this simulated surface irregularity at the same speed and the additional strain and deflection were again recorded. The tests were repeated using a variety of loaded and unloaded vehicles running at various speeds, a number of runs being made with each combination. The procedure was repeated for each trench and each pipeline.

79. It was not possible to use speeds greater than about 30 m.p.h. for the tests because of the restricted space available for acceleration. A trailer simulating one axle of the type HB road loading pattern defined in B.S.153 was run over the trenches but impact effects for it could not be determined because its maximum speed was about 2 m.p.h. However, work done at the Laboratory in which the passage of some of the test vehicles was simulated on an analogue computer gave results in good agreement with those obtained in the field tests. By computer simulation the range of results was extended to higher speeds and loads than those which it had been possible to employ in the tests.

80. The apparatus used to measure strains in the pipes was not suitable for recording static strains. Impact factors were therefore determined by dividing the additional strain induced in the pipe when a vehicle travelled over the surface irregularity by the additional strain induced when the same vehicle had a smooth run.

81. The results of the experiments showed that impact factor as defined in the preceding paragraph depends inter alia on axle load, type and speed of vehicle, and the characteristics of the springs and tyres of the vehicle. They indicated that it is not affected by the size of pipe, its depth beneath the road and the nature of the pipe bedding and the trench backfilling.

82. The results indicate the impact factors which might be expected with particular vehicles travelling at various speeds over the particular size and shape of surface irregularity used in these tests. For example they showed that an unladen light lorry of one type used would result in impact factors ranging from just over 1·0 at very slow speeds to almost 4·0 at 30 m.p.h.; the computer simulation indicated that the increase of impact factor with speed might not cease until 60 m.p.h. However, the computer simulation also showed that the maximum value of impact factor likely to be induced by the heaviest class of vehicle, the HB trailer, travelling at its maximum legally permitted speed of 12 m.p.h., was between 1·2 and 1·4 depending on the value of the suspension damping and of the wheel load.

83. For the purposes of pipe sewer design we are interested principally in the maximum effect produced by any vehicle which is likely to travel over the pipeline under impact conditions, i.e. the maximum value of the product of the surface load and its appropriate impact factor. The experiments showed with reasonable certainty that the greatest strains under impact conditions are likely to result from heavily loaded axles, although they give smaller impact factors than lightly loaded axles. They also indicated that the strains induced by the HB load recommended in Special Report No. 32, allowing for an impact factor of between 1·2 and 1·4, are likely to be greater than the strains induced by any lighter vehicles with the impact factors appropriate to the maximum speeds at which they are likely to travel at the present time or in the foreseeable future.

Joint meeting of the Institution of Civil Engineers and the Institution of Municipal Engineers

84. We were anxious to obtain the views of a wide cross-section of the engineering profession on the results of the two programmes of experiments. The Institution of Civil Engineers and the Institution of Municipal Engineers kindly agreed to arrange a joint meeting at which papers on the work were presented on 23rd January 1967.

85. Our own pilot programme is fully described in the paper entitled "Pilot experiments to determine the loads causing failure of sewer pipes under roads" by I. H. Hainsworth, M.I.C.E.; F. P. Potocki, B.Sc.; J. J. Trott, B.Sc., A.Inst.P.; and O. C. Young, B.Sc., A.M.I.C.E. Copies of the paper are available from the Secretary, The Institution of Municipal Engineers, 25 Eccleston Square, London S.W.1 (price 10s. 0d.). A full record of the impact tests is contained in the paper entitled "Impact tests on pipes buried under roads" by J. Page, B.Sc., which has been published by the Road Research Laboratory as their Report No. 35.

86. We are indebted to the two Institutions, and in particular to the President of the Institution of Municipal Engineers, Mr. Granville Berry, for arranging the meeting; and to the authors for preparing these valuable papers. We also

noted with interest and have had regard to the contributions made by many speakers in the discussion which followed the presentation of the papers. A report of the discussion will appear in the Proceedings of the Institution of Civil Engineers, Volume 38, September 1967; and was included in the Journal of the Institution of Municipal Engineers, April 1967.

Consideration of the results of the experimental work

87. The loading tests carried out at MEXE were essentially of a pilot nature and their results must be viewed in this light.

88. Due to the difficulties involved in making long-term measurements underground of slowly varying strains, many of the gauges gave anomalous readings in respect of the static strains induced by the fill loads. This was disappointing and the results that we have quoted are necessarily based on the relatively small proportion of the total number of gauges that were installed that proved to be reliable. The results must therefore be viewed with caution and we regard them only as giving an indication of the order of discrepancy which may arise in some circumstances from the application of the Marston theory to the determination of fill loads.

89. Greater reliance can be placed on the measurements of the effect of repetitive surface loads. It is easier to measure short-term changes in strain and for this purpose the strain gauges operated more reliably and a greater number of them yielded usable data. The tests indicated that current design theory significantly over-estimates the surface loads transmitted to the pipes. It must be remembered, however, that in this case the loads were transmitted through a road, for the load-spreading properties of which the theory makes no allowance. In practice there is a risk of vehicle loads being imposed on sewer trenches before adequate road reinstatement is carried out. Firm conclusions cannot therefore be drawn until the experiments can be repeated in such a way as to determine the contribution made by the road in reducing the loads transmitted to the pipes.

90. The surface loading tests were also deficient in other respects. The loads, although intended to simulate the effect of wheel loads, were applied and removed far more slowly than would have been the case with even a slow-moving vehicle. Each load was applied a small number of times compared with the thousands of heavy axle loads which occur on a trunk road even in the space of one year. If it had been practicable we would have preferred to have used smaller increments of load, and to have applied the loads much more quickly and a far greater number of times.

91. Despite these criticisms we consider that the pilot experiments fulfilled their purpose. They showed that it is practicable to establish a technique for carrying out the major programme that we have in mind, and they gave valuable experience of the problems likely to be encountered, not least in the instrumentation field. They provided insufficient evidence to justify our recommending sweeping changes in the methods and criteria at present in use for the rational design of underground pipe sewers but they highlighted the urgent need for further research and the possible economy which might result from increased knowledge.

92. The information provided by the impact tests was more reliable and we consider that on the basis of it we can make immediate recommendations for some economy in this respect by comparison with the criteria suggested in Special Report No. 32. Further work on impact factors and increased knowledge of vehicle loads may result in the possibility of further economy and would certainly give increased confidence in the criteria to be used.

93. We noted with interest that the impact factors obtained by measurements of strains in buried pipes were equal to those obtained by using an electronic weighbridge installed in the road surface. Such measurements are easier to make than experiments involving the construction of an experimental road with pipes embedded under it and should facilitate further work on impact factors.

The supporting strength of the pipeline

94. Even assuming that it will eventually be possible to determine the loads to be carried by a sewer pipeline with reasonable accuracy, the engineer will still be left with his main task, to design an economical pipeline with sufficient strength to support these loads.

95. The overall structural strength of a pipeline depends on the strength of the pipes themselves and on the type of material on which they are bedded. Advances in manufacturing techniques have provided the engineer with a wide range of pipe strengths. It is now open to him to provide adequate overall strength by using a stronger pipe and a bedding with a lower supporting strength, or a weaker pipe and a bedding, supplemented if necessary by all-round protection, with a higher supporting strength.

96. In order to calculate the overall strength which will be achieved it must be possible to predict the strengthening effect, or bedding factor, of the various materials on which pipes can be laid.

97. Bedding factors are suggested in Special Report No. 32 for the natural trimmed bottom of the trench, for granular material, and for plain and reinforced concrete beds. These factors, which are also in general use in the United States, originate from work carried out at Iowa about 1920, supported by experiments at Ohio about 1955.

98. This work was carried out principally in the laboratory and we can find no record of any extensive field-scale experimental evidence to support the bedding factors in current use. So far as we can discover there is no extensive work in progress or in mind on this subject in this country or in the United States.

99. We have also sought evidence in respect of the strengthening effect of concrete bed and haunch and concrete surround, the traditional methods of providing additional strength to sewer pipelines in this country. A very limited amount of work on this subject was done at Iowa by Schlick in 1929 and at the Building Research Station by Clarke and Young in recent years. There is little information and no field-scale experimental evidence on which to base the rational design of these two methods of strengthening sewer pipelines (see paragraph 168).

The structural design of lines of flexible pipes

100. The use of flexible pipes, other than steel, for gravity sewers has so far been confined principally to the smaller sizes. New materials of a flexible nature, particularly various plastics, are being developed rapidly and there are indications that such materials may be used more in the future for this purpose in a wider range of sizes.

101. The structural behaviour of flexible pipes in the ground is different from that of rigid pipes and to a large extent, because they deform under load, they derive their overall strength from the materials with which they are surrounded. Their theoretical design involves a fundamentally different approach from that used for the design of rigid pipes. At present in this country the design of flexible pipes, including their wall thickness, is based largely on practical experience. Since this experience is necessarily limited in respect of their use as sewers this cannot be regarded as a satisfactory or acceptable situation.

102. Some theoretical work, supported by limited observations of existing pipelines in the field, has been and is being done in the United States on this subject and theories have been evolved for the design of flexible pipes. Field-scale experimental evidence is required before we could recommend the adoption of any of these theories for general use.

The present position

103. The present position in respect of structural design of sewers is therefore that

(a) the Ministry recognises two approaches to the structural design of pipe sewers constructed with rigid pipes which can result, in a significant range of circumstances, in pipelines of substantially different strength and cost;

(b) examination of the record of behaviour of existing sewers in the ground is unlikely to assist in the short-term in assessing the structural sufficiency of sewers constructed in accordance with the traditional K29 rules because of the difficulties both of determining the incidence of failures and of obtaining sufficient detailed information regarding the original method of construction of the pipelines concerned to diagnose the causes of failure;

(c) the rational design theory in most common use is based on experimental work carried out many years ago and we can find no evidence of any recent work to determine the actual loads imposed on pipes or of their supporting strengths in modern working conditions;

(d) we have carried out a series of pilot experiments which we consider to have shown that it is practicable to establish a technique for field-scale experimental work designed to determine these matters;

(e) the Road Research Laboratory have carried out a series of impact tests which have provided valuable information on the impact effects of moving vehicles on underground pipelines in a limited range of conditions;

(f) the work that has so far been completed is quite insufficient to enable us to offer well-based guidance on the structural design of pipe sewers constructed with rigid pipes;

(g) information on the structural design of pipe sewers constructed with flexible pipes and practical experience of their use are even more limited and until laboratory and field-scale research can be carried out we are unable to offer any guidance on this subject.

We discuss in Section C of this report the information that is required and how it may be obtained, and offer our views on a reasonable approach to design whilst the necessary work is being carried out.

Section B — Practical considerations in the design and construction of sewers

104. It cannot be stressed too highly that the variants in sewer design and construction make practical considerations of great importance. We offer below our comments on some of the practical matters which the engineer will have to bear in mind if he is to achieve satisfactory and economical construction and maintenance of sewers.

Sewer and drain sizes

105. We referred in our first interim report to the vast range of drainage work, which may extend from a contract for the construction of an extensive main sewerage system, carried out by competent civil engineering contractors or direct labour organisations under the expert supervision of experienced engineers, to the drainage within the curtilage of a single dwelling house, which may be carried out by an inexperienced builder without sufficient supervision.

106. All of the information we have obtained since that report was written has accentuated the need to recognise the importance of the tributary drains connected to the public sewers, drains which form a large proportion of the total length of the whole drainage network. It is not easy to arrange for adequate inspection of the construction of such drains but it is essential that it be provided. It should be borne in mind that cracked and leaking drains can involve much unnecessary expenditure of public money by adding heavily to the cost of maintenance of sewerage systems and to pumping and treatment costs.

107. We also suggested in our first interim report that it might be practicable to divide sewers into arbitrary size ranges, for each of which economical and practical considerations would call for different design and constructional treatment. We still consider that special considerations apply to small-diameter pipelines, i.e. 9 in. diameter and under. Not only do they form a preponderant proportion of the mileage and capital investment on sewers and drains in this country but they are likely to include most of the drains designed by those with least skill and experience, and constructed with the poorest quality of workmanship and supervision.

108. We have therefore prepared a note of guidance on practical considerations in the structural design and in the construction of small-diameter sewers and drains, which we are submitting as a separate document concurrently with this report. The note does not contain many revolutionary new ideas; it is intended

to set out, particularly for the less experienced, some of the matters which must be borne in mind in constructing this class of drainage pipeline. It covers the use of both rigid and flexible pipes and amplifies the note on the laying and backfilling of the latter which appeared as an appendix to our first interim report. We recommend that the document be disseminated as widely as possible amongst those directly concerned with design and construction, whether on a major or minor scale.

109. In respect of pipes over 9 in. diameter we now doubt whether further division into size ranges will be practicable or necessary. The limited investigation of costs which we have so far been able to undertake has not shown any ready division on economic grounds and we do not consider that practical considerations alone will call for basically different design and constructional treatment of different size ranges.

110. We recognise that for sewers and drains of 9 in. diameter and under design charts and tables will be produced, since the cost of individual design from basic principles will not often be justified by the saving which may accrue. We also recognise that engineers and manufacturers are likely to produce charts and tables for the design of larger sizes of pipeline. Later in this report (paragraph 236) it will be seen that we ourselves hope to have a document prepared to replace Special Report No. 32, which would in fact include a table of loads for some sizes of pipe.

111. Nevertheless, the extensive use of such documents leads to a danger, especially on the part of the young engineer, of ignoring the criteria and practical requirements on which they are based. Pipe sewers, particularly of the larger sizes, are complex engineering structures and it must not be forgotten that design charts and tables are only tools to facilitate the application of engineering judgment and practical experence which are essential to their design. For many sewers in the medium size range and for all large sewers individual design from basic principles, which will allow the application of criteria to suit the particular conditions of each case, will be justified in the interests of reliable and economical design and construction.

New materials

112. An ever increasing range of new pipe materials is appearing on the market. Before they are extensively used there should be available adequate evidence of their capability of fulfilling the functions required of them; and definitive advice based on proven field experience on how the pipes should be laid to attain the performance required of them having regard to their special characteristics. True economy in sewer construction can only be effected by careful consideration of all the materials available, their suitability in the conditions expected to be encountered, and the relative total costs of construction using them. If the manufacturer does not assist in the task of determining the best way of using the new materials he is offering, the engineer will be inclined to avoid them. If the engineer and the ultimate user do not assist in this field, they may well miss the opportunity of effecting economy in or improving the standard of sewer construction. It is a task in which there is scope for close co-operation between the manufacturer, the engineer, local authorities and research establishments to their mutual benefit.

Pipe certification mark schemes

113. We have discussed with representatives of the British Standards Institution their pipe certification mark schemes. The ultimate responsibility for ensuring that a product is of the required quality will always rest with the manufacturer and the purchaser. One of the best assurances of quality is that the manufacturer's reputation rests on it and we have no doubt that the quality of pipes used for sewers in this country is generally high. Nevertheless, engineers have to decide to what extent it is necessary to check quality by inspection and testing, and in this respect many engineers place much dependence on the Institution's certification mark schemes. No such scheme can be an absolute assurance of the quality of every pipe produced but the inspection and testing services operated in connection with certification mark schemes should be of sufficient value to justify the assurance they imply and the confidence placed in them. We are pleased to hear that the Institution are discussing with the Pipe Associations concerned means whereby the existing pipe certification mark inspection and testing services can, within reasonable economic limits, be improved. We look forward to hearing of their progress.

Dimensional standardisation; size and strength classification

114. We have commenced discussions with the Pipe Association principally concerned regarding the view expressed in our first interim report that insufficient attention was being given to dimensional standardisation in sewer pipes. They have drawn our attention to the difficulties of complete dimensional standardisation with the present large numbers of different sizes and strengths of pipes and with the possibility of metrification of pipe sizes in the foreseeable future. We have set up a sub-committee including representatives of the Association to consider how these problems may best be solved, including the possibility of a reduction in the range of size and strength classifications.

115. The existing British Standard Specifications are in effect performance standards, whereas the equivalent American Specifications are strict design and dimensional standards in that for example they specify such requirements as the amount of circumferential reinforcement and the pipe wall thickness. It is interesting to find that there is now a body of opinion in the United States which favours Specifications more nearly of a performance type with a view to allowing more scope for economic design, although the proposals they have in mind would still not give the extent of dimensional freedom permitted by British Specifications.

116. It was our original view that only such dimensional tolerances should be permitted in sewer pipes as would permit the use of pipes and fittings from different manufacturers in the same pipelines. This remains a theoretically desirable aim but we are no longer convinced that it would be economically justifiable. It would involve re-writing British Specifications as strict design and dimensional standards and this might not be in the interests of progress and economy in the design and manufacture of pipes. The answer may lie in performance standards such as exist but with some increased dimensional standardisation, for example of internal diameters. Despite the difficulties of manufacture we remain convinced of the need to be able to obtain junctions and bends of the same strength and dimensions as the pipes between which they are to be installed.

117. Our representatives noted during their visit to the United States that the only requirement in respect of curing period for concrete pipes is that it shall be sufficient to ensure that the concrete has developed the specified 28-day compressive strength; pipes are deemed ready for acceptance as soon as they fulfil the test requirements laid down in the appropriate Standard Specification. In practice this frequently means that it is permissible to despatch pipes from the factory within a relatively short period of manufacture. A more practical approach is taken, particularly at site supervision level, to the necessary surface finish of the pipe, especially of the exterior; and no obligation is laid on manufacturers to provide an unblemished surface, if there is no detriment to the purpose for which the pipe is to be used. A greater range of aggregates for concrete pipe manufacture is permitted, the only real criterion being that they must result in a pipe of the required quality. Far more use is made of vertical casting processes than in this country. We hope that the sub-committee referred to in paragraph 114 will consider these and any other matters which may lead to economy in manufacture whilst still maintaining acceptable quality in the product. We look forward to continuing our discussions on this subject.

Pipe gradients

118. We suggested in our first interim report that engineers should continue to specify and require sewers to be laid at definite gradients and that only constructional methods which catered for this requirement should be used. On further reflection we are of the opinion that this statement requires qualification.

119. Where sewers have to be laid at flat gradients the need for precision in maintaining grade is obviously greater than would apply to a sewer laid at a comparatively steep gradient.

120. We consider, however, that if any deviation from level of individual pipes is to be permitted, the extent of tolerance which will be accepted should be precisely defined in the specification and should not be left to the site engineer to decide. Fair tendering, economy and satisfactory construction can only be achieved if both the contractor and the resident engineer know exactly what is required and what tolerance, if any, will be accepted.

Pipe joints

121. In our first interim report we set out the advantages of mechanical joints* for rigid sewer pipes. They can be made quickly and easily and have the added advantage of providing flexibility in the sewer. The evidence we obtained regarding failures stressed the deficiencies of rigid joints and we are convinced that the use of mechanical joints should become virtually universal as soon as manufacturing facilities make this practicable, particularly for foul sewers. The only proviso we would make is that there may be some circumstances, for example a sewer bedded on or surrounded with concrete laid on a

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* Mechanical joints referred to in this report are joints with factory-made jointing materials. These are often called flexible joints, although the amount of flexibility provided is sometimes small, particularly with large-diameter pipes.

firm foundation, where the use of mechanical joints might not be justified. It will be seen in our note of guidance on practical considerations in the structural design and in the construction of small-diameter sewers and drains (see paragraph 108) and in paragraphs 151 and 184 of this report that we consider it particularly important that mechanical joints should be employed where pipes are bedded on the natural bottom of the trench or on granular material.

122. We also referred in our first interim report to questions having been raised recently regarding the life of rubber rings in mechanical joints, arising from reports of degradation received from Holland and Australia. Despite extensive inquiries neither we nor the British Standards Institution committee concerned with rubber for joint rings have found any evidence of degradation having occurred in this country. Our representatives also made inquiries on this subject during their visit to the United States and received no reports of degradation having occurred there.

123. We consider that the weight of evidence from Holland and Australia, where different soil, climatic and water supply conditions prevail and where the quality of rubber in use may have been somewhat different, is not sufficient to justify any material doubt in the minds of engineers regarding the suitability of rubber rings in this country for this purpose.

124. Nevertheless, in order to provide evidence to substantiate this view we have initiated long-term trials of rubber rings in field conditions at Bracknell, Coventry and Ipswich. In one series of tests rubber rings, mounted on formers designed to reproduce conditions in a joint, will be immersed in tanks through which sewage will be passed continuously. In a second series sample rings will be employed in the joints of sewers laid underground in field conditions and sewage will be passed continuously through these pipelines. Rings will be removed and examined at intervals and we expect the tests to continue for several years. We are appreciative of the help of the Clay Pipe Development Association Ltd. and the Concrete Pipe Association who are supplying the necessary materials free of charge; of the three local authorities who are undertaking the tests for us; and of the Rubber and Plastics Research Association who are advising us and will be responsible for the examination of the rings. We would stress that the tests are being carried out only because we think that in view of the question that had been raised it would be undesirable to leave any doubts in the minds of engineers on this subject.

Sewer lines; manholes and their spacing

125. Our representatives noted that it is not uncommon practice in the United States to lay sewers on horizontal and vertical curves. In at least one area they visited the practice is extended down to the smallest sizes of pipes, and by means of short bevel pipes to curves of quite small radius. It is contended there that curves on sewers present no significant maintenance problems and allow manhole spacing to be increased and to be limited only by the practicability of cleaning with the modern plant available for this purpose.

126. The Ministry at present requires in Form K29 that manholes shall normally be provided at all changes of direction and gradient and at distances not exceeding about 120 yds. It suggests that in sewers in which men can work this distance may be increased but makes no definite recommendations in respect of the maximum spacing which might be permitted in such cases.

127. Completely contrary views have been expressed to us regarding these requirements. Some engineers contend that manhole spacing on small sewers could be increased without detriment and with substantial economy. Others submit that it is impracticable to clear blockages with the equipment available to them where manholes are 120 yds. apart; they therefore always design on closer spacing, e.g. 90 yds.

128. The questions of sewer lines, manhole spacing and sewer maintenance are obviously inter-related. We can see no objections to horizontal curves of reasonable radius on sewers in which men can work but we are prepared to go no further than this at the present time. There is no doubt, however, that the cost of manholes is a substantial proportion of the total cost of a sewer. The problem of whether the development and general availability of improved and modern maintenance equipment would allow increased manhole spacing without detriment and with overall economy is one worthy of investigation and we will consider what steps can be taken to this end.

129. We noted with interest that increasing use is being made in the United States of thick-walled manhole sections with rubber gasket joints, which do away with the need for in-situ concrete surround. Manholes are a frequent source of infiltration problems; this method of construction might assist in reducing these problems, we would hope without increased expenditure.

Junctions

130. Defects frequently occur at junctions on sewers. To avoid additional excavation it appears to be a common practice to bring the connection vertically up from the junction and to surround it with concrete. This results in the need to provide increased supporting strength beneath the junction by means of a concrete bed if damage is to be avoided. Where granular bedding is being used this results not only in interruption of construction but in non-uniform support along the length of the pipeline and a risk of differential settlement.

131. Care in design and the use of mechanical joints adjacent to points of connection may prevent, without significant increased expenditure, the occurrence of subsequent costly defects at or near junctions. We suggest that wherever possible connecting pipes should be brought up at an angle from the vertical at least sufficient to avoid the imposition of increased loads on the main pipeline, even if this entails some increased excavation for the side drain. Concrete protection for the connection will still be necessary in many cases but it should be so constructed that its weight is not borne by the sewer.

132. Some research has been done in the United States on the relative effects of 45° and 90° angles of entry into sewers, which indicates that the use of 90° junctions has insignificant effect on hydraulic characteristics in most cases, especially with small-diameter pipes. The use there of 90° junctions with short blind tee sockets (knock-outs) for future connections is increasing. Connections to sewers are traditional points of weakness and the use of 90° angles of entry and short tees are interesting developments which might reduce risk of damage.

Bedding materials for rigid pipes

133. We have referred earlier to the fact that in many cases the engineer will find that various combinations of different pipe strengths and different beddings are capable of carrying the calculated loads. For example in a particular case it may be open to him to select a class 5 pipe laid on granular bedding, a class 3 pipe laid on a concrete bed or a class 1 pipe surrounded with concrete.

134. In deciding which combination to use he will then have two principle matters to consider:—

(a) the relative overall cost of the completed sewer using different combinations of pipes and beddings;

(b) the practical advantages and disadvantages of various beddings and the methods of construction associated with their use in the particular conditions likely to be encountered.

135. The two matters are obviously closely related; in some cases practical advantages and disadvantages will be clearly reflected in relative costs.

136. In other cases, however, relative costs may not vary significantly and the engineer will have to reach a decision principally on the basis of the practical advantages of the various forms of bedding. He will have to consider not only the advantages from the constructional aspect but also, so far as is possible, the effect on subsequent maintenance of the sewer.

137. We offer below some comments on practical considerations in the relative merits of various forms of bedding, which are intended to assist the engineer by drawing to his attention particular matters to be borne in mind when considering what bedding material might be used in various circumstances. We have sought the views of a wide range of practising engineers on this subject; as might be expected there are wide divergences of opinion, related partly to the size, type and purpose of the sewers with which each engineer has been principally concerned and the ground conditions and location in which these sewers were laid. Our comments are the best that we can offer in the light of present knowledge and experience but the variables in sewer construction obviously provide scope for differing opinions and further experience will be the true test of what is best in particular circumstances.

138. We would stress that whatever bedding may be selected by the engineer, it is essential that there shall be a satisfactory quality of workmanship and adequate supervision in all cases.

(a) *Imported granular bedding*

139. The use of imported granular material for bedding pipes helps to meet the need for increased mechanisation of sewer construction in that extensive hand trimming of the trench bottom is unnecessary. If an adequate thickness of granular bedding is provided, the excavation of socket holes in the natural formation is also unnecessary in most circumstances; socket holes should, however, be excavated in the granular bedding itself before the pipes are laid and it is essential that there should be no risk of the sockets bearing directly on the natural trench bottom.

140. Granular material is easy to handle, it protects the trench bottom and enables construction to proceed in most weather and subsoil conditions. Backfilling of the trench can proceed immediately the sewer has been laid and tested. The trench is open for a minimum of time and the length of the working area can be reduced to that necessary for adequate testing and inspection.

141. To provide proper support for the pipe it is essential that the granular material shall be adequately compacted. The extent of compaction necessary will vary according to the grading of the material. Some well graded materials can be adequately compacted without great effort. Poorly graded materials will require careful compaction in layers, preferably with suitable machines. The greater the amount of fine particles the greater will be the risk of settlement unless compaction is carefully controlled.

142. A suitable material is broken stone or gravel from $\frac{3}{8}$ to $\frac{3}{16}$ in. in size since it requires little tamping, but coarse sand, or sand and gravel, or gravel from $\frac{3}{4}$ in. down as it comes from the quarry is acceptable provided it complies with the Building Research Station tests described in Appendix A to this report. In wet fine grained soils coarse sand in the bedding reduces the intrusion of foundation soil into the voids. An excess of fine particles, however, makes the mixture more difficult to compact when damp. Sands containing fine particles in sufficient quantity to impede drainage or cause bulking during construction should not be used.

143. Materials of other gradings may also be satisfactory, provided that they comply with the requirements of the tests described in Appendix A. If larger material than that suggested above is used, there is likely to be increased difficulty in laying the pipes accurately to line and level and in placing and spreading the material. There is also the risk that individual large particles may cause excessive local concentrations of pressure on the pipes.

144. Inadequate compaction or the use of unsuitable material can result in

(a) non-uniform support along the pipe length, resulting in some reduction in supporting strength or bedding factor;

(b) vertical shear at joints, causing extra stress in the sockets;

(c) reduction of pipe bedding angle, again resulting in some reduction in bedding factor;

(d) uneven settlement of the pipe, resulting in a change of gradient;

(e) washing of backfilling material or natural soil from the trench bottom or walls into the granular bedding, resulting in subsidence and the risk of damage to adjacent services.

145. A factor which must weigh in a decision as to the use of granular bedding is local availability of material. In their specifications engineers should allow the use of as wide a range of materials as are satisfactory, so that contractors may select the material which they can most readily and economically provide bearing in mind the need for adequate compaction and the relative difficulty of achieving this with materials of different gradings.

146. The use of granular bedding involves some risk of loss of the granular material, and hence disturbance of the pipes and other services, if excavations at a greater depth are made immediately alongside the trench at a later date.

147. There is a risk of the bedding acting as a permanent drainage channel for subsoil water. It may be necessary for water stops to be constructed in some ground conditions to prevent the passage of water along the trench.

148. Care is necessary in the withdrawal of trench supports to ensure that granular bedding is not disturbed.

149. In some cases the use of granular material rather than concrete will involve the provision of extra strength pipes to achieve the necessary overall strength. As the size and weight of pipes increase there are consequent increased difficulties of transport and handling and larger plant is required. The location and means of access to the site and the risk of disturbance in residential areas must be borne in mind.

150. The use of granular bedding, particularly with larger diameter extra-strength pipes, involves a risk of settlement; correct grading of the bedding material reduces settlement to a minimum. The engineer must consider whether the consequent risk of deviation from line and/or level can be accepted bearing in mind the purpose and required capacity of the sewer.

151. Granular beddings are by their nature flexible and where they are used the pipelines should be constructed with mechanical joints. In areas where subsidence may be expected, e.g. mining areas, care should be taken in constructing the joints to ensure that the granular material does not enter the sockets and cause damage to them if subsequent movement takes place.

152. Special care is necessary to provide adequate support for junctions where granular bedding is used.

153. In many circumstances granular material possesses substantial advantages for bedding sewer pipes, particularly of the small and medium size ranges. In considering its use engineers should particularly bear in mind availability of material; location of and access to the site; risk of slight deviation from line and level, especially with larger diameter pipes; and likelihood of subsequent deeper excavation immediately adjoining the sewer trench.

(*b*) *Excavated material*

154. In some cases the material excavated from the trench may be a granular material satisfactory for use as bedding for the pipes. The same comments apply as in paragraphs 139 to 153 but special care is necessary in selecting the excavated material to be used, because it is likely to be less uniform in quality and grading than specially imported material.

155. Only a limited range of soils will be suitable for this purpose; they must be free-draining and capable of being compacted sufficiently to provide support for the pipe. A simple method devised by the Building Research Station for assessing the suitability of excavated material for use as bedding is described in Appendix A to this report. Only material complying strictly with the requirements of these tests should be considered for use.

(*c*) *Concrete bed*

156. Concrete can be used to provide a positive, uniform and satisfactory bed for sewer pipes but it must be properly laid and of satisfactory quality. Its use

reduces the risk of damage to the pipeline by subsequent excavations alongside the trench. The laying of pipes accurately to gradients is facilitated, especially with sewers over 12 in. diameter. In most cases the removal of the trench supports is unlikely to affect the stability of the bedding. The additional supporting strength which concrete provides may enable lower strength pipes to be used, which reduces difficulties of transport and handling, particularly of large size pipes. This type of bedding facilitates the proper support of junctions and other services.

157. Care must be taken in placing the concrete, particularly in adverse subsoil conditions, to ensure that it provides a uniform bed for the pipes. In bad and wet ground conditions it is often advantageous to place an initial screed or stone rejects over the trench bottom to prevent slurrying. The bed must be laid on a firm foundation if it is to provide adequate supporting strength.

158. The quality of concrete required must be specified. Until further evidence can be obtained it is suggested that the concrete should be such as to provide a minimum works cube strength at 28 days of 3,000 lbs./sq. in.

159. Proper control of quality and supervision of placing of the concrete are essential. Any relaxation of control or supervision may result in voids, especially under the invert, with a consequent serious reduction in the supporting strength of the bedding.

160. It is necessary to allow a concrete bed to set sufficiently to attain the strength required to bear the loads to be imposed on it during backfilling of the trench before this is carried out. In the absence of adequate information on this subject we have made some arbitrary suggestions in respect of the minimum setting periods to be allowed in our note of guidance on practical considerations in the structural design and in the construction of small-diameter sewers and drains. For larger sewers the strength to be attained before backfilling commences and vehicle loads are imposed on the trench should be assessed, so far as this is possible, and laid down in the specification; if possible the time likely to be required to attain the strength in different conditions should also be indicated in the specification.

161. The time required for the concrete bed to attain the strength required may involve some delay in completion of construction and increase the length of the working area. The importance of this will vary according to the location of the site and the contractor's organisation of his construction programme.

162. Frosty weather is liable to delay construction where a concrete bed is used, unless pre-heating methods are employed; such weather, however, is also likely to delay backfilling and the completion of construction whatever bedding is used. Construction can continue with concrete bedding in most other weather conditions. Maintenance of the quality of the concrete may be more difficult in very wet weather or subsoil conditions.

163. Where flexibility of a pipeline is considered to be essential it is necessary to form cleavage planes in the concrete bed. This should be done by the provision of vertical construction joints giving a gap of at least ½ in. at intervals of not more than about 16 ft., but always at a pipe joint. This is practicable but obviously involves additional labour and time in placing the bed. Care must be taken to ensure that movement at these points is not prevented by concrete

finding its way into the gap between spigot and socket. The material used for forming the construction joint in the bed should be carried up and shaped round the spigot and should abut on the socket.

164. Where site access is not easy, particularly where sewers are to be laid in open country, some difficulty may arise in transporting and placing in position satisfactory concrete. Care must be taken to ensure that partially set or otherwise unsatisfactory material is not used.

165. There is no objection to the concrete bed extending to the sides of the trench if this proves to be desirable from the constructional aspect.

166. Concrete is a useful and satisfactory bedding material for sewer pipes of all sizes in most circumstances. In considering its use the engineer should particularly bear in mind the location of and access to the site; the weather conditions likely to be encountered during the contract period; and whether delay in backfilling is likely to have any serious effect in the conditions of the particular scheme.

(*d*) *Concrete bed and haunch and concrete surround*

167. The comments on concrete bed generally apply also to concrete bed and haunch and concrete surround. To achieve the full strengthening value of concrete surround, particular stress should be placed on the control of the quality of the concrete and the supervision of its placing. Properly designed concrete surround may have special value with very large diameter pipelines, because in some site conditions the use of extra-strength pipes may result in difficulties in transport and handling.

168. We have already referred to the lack of information regarding a basis for the rational design of concrete bed and haunch and concrete surround. At this stage we can only suggest that reference might be made to the information given in the American Society of Civil Engineers Manual of Engineering Practice No. 37, "Design and Construction of Sanitary and Storm Sewers". The information in the Manual on this subject is believed to be based largely on the work of Schlick (see paragraph 99).

(*e*) *Reinforced concrete bed, bed and haunch, and surround*

169. It is considered to be generally undesirable to introduce the complication of reinforcement of in-situ concrete into pipelaying, if it can be avoided by the use of other combinations of pipe strength and bedding. There will probably be practical difficulty in placing and fixing the reinforcement, particularly in concrete bed, and in ensuring its cleanliness in the conditions likely to be encountered.

170. Reinforcement is rarely likely to be essential except with the largest sizes of pipe. The design of such pipes should be considered as structural problems to be undertaken only by engineers experienced in this field. In these cases the surround will be a reinforced concrete structure, with the pipe acting mainly as an internal shutter and permanent lining; constructional methods suitable to the structure will be necessary.

171. The use of reinforcement may be worthy of consideration where conditions which had not been foreseen are encountered and no other method of providing necessary additional strength in the pipeline is readily available.

(*f*) *Concrete arch (plain or reinforced)*

172. The use of a concrete arch rather than a concrete bed to achieve the required supporting strength for the pipe offers some advantage in the ease of placing of the concrete. Accidental damage to the pipe from careless backfilling or later re-excavation is less likely. Joints in the concrete are easier to form.

173. Where an arch is used, however, the pipe must still be satisfactorily bedded. Future connections to the pipe may be more difficult to construct. Because of the increased breadth of the structure at the top, the total load may be increased, particularly at shallow depths under roads.

174. This method of bedding and protection has not so far been widely used in this country. It seems likely that the labour entailed and time taken in placing both bedding and arch will be at least as great as in placing a concrete bed and carrying out normal backfilling.

175. The use of a concrete arch is a convenient method of strengthening pipes already laid, to cater for higher loadings than those for which they were originally designed.

(g) *Bearing piles*

176. Bearing piles should be used only where the pipe must remain fixed even though ground movement may take place and where ground conditions make any other form of support unsatisfactory.

177. The pipeline and its support must be of adequate strength, as beams spanning between the piles, to bear the superimposed loads. Flexibility must be provided at the bearing piles. Care must be taken to provide adequate anchorage of the pipes to the piles to guard against the risk of flotation. The use of piles necessitates individual structural design of the particular pipeline concerned, which should be entrusted to an experienced engineer.

(*h*) *Natural trimmed bottom of the trench*

178. The laying of sewer pipes on the natural trimmed bottom of the trench has the obvious advantage that it is unnecessary to import any bedding material onto the site.

179. To achieve uniform support of the pipes it is essential that the trench bottom shall be accurately prepared to the required grade. If the barrels of the pipes are not in uniform contact with the ground throughout their length, unequal and increased stresses could be set up in the pipes.

180. To a very great extent trench excavation is carried out by machine. Where pipes are laid on the natural bottom hand trimming will be necessary, as well as the formation by hand of socket holes. In order to produce a truly uniform

bed it is essential that this hand trimming shall be carried out carefully and accurately under close supervision. It is practicable to produce the type of support envisaged by a bedding factor of 1·1 only in suitable subsoil conditions. If the ground is either too hard or too soft, accuracy of grade is particularly difficult to ensure. The presence of subsoil water in any quantity, or bad weather conditions, usually make it impossible to produce and maintain an accurate bed. Longitudinal curvature of individual pipes (even within the permissible limits of the relevant British Standard Specifications) increases the difficulty of ensuring uniform support.

181. If the trench bottom is accidentally overdug it is difficult, in bringing it up to level, to ensure that the replaced material is as firm as the adjoining undisturbed bottom. There is a tendency in the excavation of socket holes to make them too long and thus to reduce the bearing length of the pipe barrel.

182. Even when a uniform bed can be prepared, this results only in line contact along the bottom of the pipe. Particular care is essential in packing and consolidating suitable excavated material under the lower quadrants of the pipe to ensure uniform support. The alternative of shaping the trench bottom to the pipe is becoming impracticable in conditions of increasing shortage of skilled labour.

183. Assessment of the suitability of the ground for providing uniform support with this method of bedding can only properly be made after the trench bottom is open for inspection; judgment requires both knowledge and experience.

184. The difficulties of ensuring that the natural trench bottom provides a uniform bed are such that in our opinion, except with iron pipes, this method of bedding

(a) is not well adapted to the current trend of modern constructional techniques;

(b) should be used only where a constant high standard of workmanship and supervision can be guaranteed;

(c) should be used only for pipes of 12 in. diameter and under where dry conditions can be achieved and where the subsoil is such that accurate hand trimming is practicable;

(d) should only be used with pipes that have mechanical joints, which it is hoped will become universally available before long.

In considering the use of this method of bedding the engineer will obviously also consider whether the achievement of the necessary uniform support by accurate trimming is in fact more economical than the use of other forms of bedding.

Bedding materials for flexible pipes

185. We indicated in the appendix to our first interim report that we considered it essential that flexible pipes other than steel should be bedded on granular material, imported to the site or excavated from the trench. We have received no new evidence which would lead us to change this view.

Backfilling of trenches and surface reinstatement

186. We sought information from one hundred and forty-seven major highway authorities regarding the allegedly increasing practice of requiring sewer trenches in roads to be backfilled throughout their depth, except for a cushion of earth over the pipe, with weak concrete in place of the excavated material. We found that many of the authorities did occasionally ask for this to be done but only in special circumstances where it was essential that the road be opened to traffic immediately, for example the crossing of a major trunk highway.

187. The Road Research Laboratory tests indicated that impact factor was not affected by the nature or degree of compaction of backfilling. This is not to say, however, that the strains induced in the pipes by passing vehicles are not so affected. In fact the tests showed that the strains induced in the pipes when the trench was backfilled with loose sandy clay up to road surface level were ten times as great as with lean concrete backfilling over a cushion of earth; and twice as great as when excavated material was returned to the trench and the road reinstated. The importance of proper compaction of backfilling is evident.

188. There has so far been reluctance in this country to specify and require a definite degree of compaction, no doubt largely because it involves the provision of additional testing facilities which are not always readily available. We consider that wherever possible engineers should specify the relative density to be achieved and should seek to arrange for the testing facilities necessary to ensure construction in accordance with their requirements.

189. We also sought information regarding practice in respect of interim road surface restoration. We found that although many highway authorities require a temporary surfacing of coated macadam to be laid immediately, some still ask that the trench shall be left unsealed for periods up to fourteen days before surfacing in order to allow compaction by traffic. Many suggest that temporary surface reinstatement should be left proud of the existing road. These practices obviously result in increased impact effects on pipe sewers.

190. We sympathise with the highway engineer in respect of the problems which lead to this sort of requirement and which arise largely from inadequate compaction of backfilling. However, we hope that there may be concerted action on the part of drainage engineers to ensure improved standards of backfilling and on the part of highway engineers to ensure uniform and adequate standards of temporary restoration, which would avoid the imposition of unnecessary loads on underground pipelines. If this could be achieved and guaranteed there would be room for substantial economies in the structural design of sewers.

191. In respect of the use of weak concrete for backfilling we see no great objection from the aspect of the structural design of sewers, subject to a cushion of earth being provided immediately over the pipes. There are practical objections, however, such as the difficulty of subsequent excavation to the sewer and the possibility of interference with natural subsoil drainage. Furthermore, the cost would obviously preclude its general use. It may be valuable and necessary in certain special circumstances but we would expect

these to be strictly limited and would suggest that engineers should instead concentrate on general improvement of standards of backfilling and reinstatement.

From design to construction

192. It has been suggested that the view we have repeatedly expressed that design and construction must have regard to modern constructional techniques might be taken to imply acceptance of a lower quality of workmanship. Our aim is of course precisely the opposite and the quality both of workmanship and of the finished product must be maintained and where possible improved.

193. We are convinced, however, that this can only be done by recognising the changes in constructional techniques which are bound to occur. There is an ever-increasing shortage of skilled labour, the effect of which, without substantial increases in cost, can only be offset by increased mechanisation of sewer construction. It is the engineer's task to design and specify sewer works to cater for this mechanisation in such a way that its use will result in the most economical construction whilst at the same time maintaining the high quality of workmanship and finished product which are essential. He should remember that the more he can cater for modern constructional methods, which will in any case be used, the more easily and cheaply he will attain the required quality of finished product, the standard of which must not be allowed to and need not deteriorate as a consequence of mechanised construction.

194. A substantial contribution can be made in this respect by careful examination of specifications. They must be so written that only requirements are included which are expected to be attained and which it is intended to enforce. Out-of-date clauses should be excluded. So should clauses which lay down absolute requirements which both the engineer and the contractor know to be unattainable in practice and from which unstated tolerance will in fact be accepted. If tolerances are to be permitted their extent should be clearly defined (see paragraph 120).

195. The more a contractor is allowed to depart from a specification, whether because it contains impracticable clauses or for any other reason, the more he will expect to be allowed to depart and the worse will be the standard of construction achieved. Bad specifications lead to unfair tendering; to prices including for requirements that the engineer does not want and does not expect to attain; and to the risk of a lower quality of finished product. The need for true and practical specifications cannot be too highly stressed.

196. Increased mechanisation will not reduce the need for adequate and competent supervision. We recognise that shortage of experienced staff increases the difficulties of engineers in this respect but we can only point to the facts that poor supervision can be as dangerous as poor design; and that any reduction in supervision may well be false overall economy.

197. Shortage of staff may also encourage divorce of design from construction, a division that is to be deprecated. A design engineer with little field experience cannot write a practical specification; an engineer in charge of construction cannot appreciate the need for compliance with a specification unless he

appreciates the design behind it. However difficult it may be, every effort should be made to ensure that the young engineer has the opportunity of experience in both fields and that a close relationship is maintained between the design office and construction in the field.

The invitation of tenders and economy

198. The general practice in this country is for the engineer to specify precisely what pipe material is to be used for each contract. We were interested to note that in the United States it is normal practice for the engineer to decide what different pipe materials are acceptable, to specify the bedding and class of pipe required with each material, and to allow the contractor to offer whichever material he wishes.

199. In discussion with engineers in this country the predominant argument against the adoption of this practice has been that if anything goes wrong with the contract they may be accused by both client and contractor of not knowing their own minds. We cannot accept that this is a valid argument by the engineer, the client or the contractor, since the precise constructional requirements with each material would still be specified and the engineer obviously would not include in the list of permitted materials any he considered unsuitable in the particular circumstances of the case he was considering.

200. The provision of a satisfactory sewer involves two aspects, design and construction. There is room for more recognition that both the engineer and the contractor have their separate skills, which they should be encouraged to exercise to the full. In some circumstances only one type of pipe and bedding will be acceptable; but in many others no engineer can say, particularly in advance, that any one of a number of combinations will be more satisfactory than another, and one of his prime interests must be the saving of his client's or employer's money.

201. In such cases we think it reasonable for the engineer to specify precisely what is required with each acceptable combination but to allow the contractor to tender for that specified combination which his skill, experience, plant and labour force will allow him to construct most cheaply and efficiently. This system would create true competition both in the construction and pipe supply fields.

Section C — The information that is needed and how it should be sought

The structural design of rigid pipelines and flexible lines of rigid pipes

202. Of the two approaches to structural design at present recognised by the Ministry one is based almost entirely on practical experience and judgment and the other on rational calculation. The changes in the economic, manufacturing and constructional spheres in recent years which have brought about the need for reconsideration of the traditional K29 rules are likely to continue, perhaps at an accelerating pace, in the years to come. Sewer design methods must be capable of continuing adaptation to these changes; and fixed rules, even if brought up to date, will not fulfil this purpose.

203. Experienced engineers will not need to be reminded of the variables in sewer construction. Not only do ground conditions vary from length to length but weather conditions vary from day to day. Quality of workmanship is by no means standard. Even the quality of materials used may vary substantially.

204. These variables make it impossible to reduce design to a matter of easy reference to a set of charts. In this field of engineering, perhaps more than many others, theoretical considerations must be tempered with engineering judgment and practical experience.

205. A sewer pipeline is a structure and a rule-of-thumb approach to its design will not be sufficient to ensure safe and economical construction in the future. When sufficient knowledge is available a rational approach to its design as a structure should be adopted so far as this is practicable in the light of the large number of variables entailed. The universal adoption of rational design would not of course involve the abandonment of the traditional methods of strengthening a pipeline with in-situ concrete; if sufficient knowledge can be made available, rational design can be applied to these methods as well as to any other.

206. We are convinced, however, that we cannot offer well-based detailed advice on these matters without more practical evidence and that this can only be obtained by extensive field-scale experimental work. We set out below the nature of the research that we consider to be necessary.

(a) Loads on sewer pipelines

207. Further work similar to our pilot experiments is needed in a variety of different ground conditions, simulating more accurately the actual loading conditions likely to be encountered in practice. More repetitive loading tests

are required with a much greater number of applications of load. The comparatively high discrepancy factors in respect of surface loads point to the need for further examination of the method of calculation of the effect of these loads, including the 3 feet equivalent length of pipe on which calculations are at present based.

208. More data is needed on possible fatigue and creep effects in pipes of various materials both in the testing machine and in the ground in representative types of bedding and backfilling. Instruments should be developed capable of reliably recording the long-term strains associated with the gradual development of the full load on a buried pipe due to the backfilling and road construction.

209. Research work is needed to check the criteria used for the design of pipelines in wide trenches and under embankments, in particular the 'settlement ratio'.

210. There is a tendency for axle loads and their numbers to increase. It is difficult to predict the type of traffic likely to occur during the next few decades and extensive study of this problem is in progress by the Road Research Laboratory.

211. The impact tests have shown that impact factor increases with vehicle speed and it is essential to know the speeds at which the heavier classes of vehicle are likely to travel in future. It is also necessary to know the mechanical characteristics of the various suspension systems and tyres used on heavy vehicles in order to assess their impact characteristics. It is desirable to determine the impact effects brought about by surface irregularities of shapes and sizes other than that used in the experiments so far completed, preferably after study of the types of surface irregularity which occur in practice after trench reinstatement. There was good agreement between the values of impact factor derived by computer simulation and those measured in the field and it is obviously desirable that the field or electronic weighbridge tests be extended to include heavier vehicles and higher speeds than have so far been practicable.

(*b*) *The supporting strength of sewer pipelines*

212. We have no wish to criticise the valuable and carefully controlled work carried out at Iowa and Ohio on bedding factors but we consider field-scale experimental work to be necessary to verify that it is in fact possible to simulate in the laboratory all the many variables which apply in field conditions; and to check the bedding factors in current use. It is necessary to establish such matters as effect on bedding factor of the accuracy of trimming of the natural bottom of the trench; the effects of grading and degree of compaction of granular material; and of the mix and strength of the concrete used for bedding.

213. Opinions vary among engineers regarding the relative advantages of using extra-strength pipes and a bedding with a lower supporting strength and using a weaker pipe haunched or surrounded with in-situ concrete. Earlier in this report we have offered our views on practical considerations in the relative merits in various circumstances of various forms of bedding and protection.

In many cases modern constructional methods and standards of workmanship will lend themselves to providing the necessary strength mainly in the pipe itself, since strict control of materials should be easier to achieve in the factory than on the site. Nevertheless, we have no significant evidence which would lead us to condemn the traditional method of providing strength by means of in-situ concrete, subject to satisfactory standards of workmanship.

214. Apart from practical merits one of the factors which will weigh heavily in the choice between the two methods is relative cost. We have sought information on this question and find that such matters as variation in ground conditions, availability of natural materials in different parts of the country, the extent of competition at the time of tendering and the previous experience of contractors in the area all make it difficult, if not impossible, to generalise on the subject of costs. In any case, however, until there is more reliable data on which to determine the dimensions and other characteristics of concrete haunch or surround that are necessary with various classes of pipe to provide the same overall supporting strength as other combinations of pipe strengths and bedding materials, it would clearly be premature to attempt to be precise in the matter of comparative cost.

215. We therefore consider it urgently necessary to provide engineers with adequate information on which to base their designs of in-situ concrete protection and on which to make cost comparisons. Field-scale experiments supported by laboratory work are needed to determine the strengthening effect of concrete bed and haunch and concrete surround. They should cover such matters as the relationship between strengthening effect and the mix, strength and thickness of concrete; the effect of carrying the haunch to different heights up the pipe and of carrying the concrete to the trench walls; and the extent tc which it is necessary to allow concrete to mature before trenches are backfilled and vehicle loads imposed on them.

The structural design of lines of flexible pipes

216. We have referred to the lack of a proven theory for the rational design of lines of flexible pipes. The prospect of increasing use of flexible materials makes laboratory and field-scale research work to assess design methods and criteria for such pipelines urgently necessary. If it is not done we shall again be faced with the situation that an increasing range of new materials is being employed but the engineer has inadequate information regarding the design and constructional requirements associated with their use.

The justification for the work

217. Our pilot experiments were carried out to assess whether a major programme of research would be worthwhile and practicable. We are convinced that they have shown that such a programme could and should be carried out. Research purely for the sake of increased knowledge is desirable but in the present case there is much greater justification for it being done.

218. We have already pointed out that the Ministry accepts two approaches to the structural design of sewers which may give significantly different answers;

and that either the one will result in extravagant and unnecessarily costly construction or the other may ultimately lead to the risk of an unsatisfactory end product and the dangers and expenditure consequent upon it. We submit that neither alternative is satisfactory or permanently acceptable.

219. We have sought to establish the total amount expended annually in this country on underground drainage work. It must be remembered that the field covers not only public sewers and private domestic drainage but also industrial and highway drainage systems. We have found no means of accurately assessing this figure but we believe that a total of at least one hundred million pounds is spent every year on underground drainage works and that the figure may well be substantially greater.

220. The pilot and impact tests that have been carried out will help us to make some interim suggestions in respect of rational design criteria which should effect some saving in cost by comparison with the criteria in current use. We are convinced that increased knowledge is likely to result in further economy, either on the one hand by allowing less generous design and a consequent saving in capital expenditure, or on the other by ensuring higher standards of construction and avoidance of the risk of failure, which might in turn reasonably be expected to reduce operational, maintenance and renewal costs.

221. The fact that a reduction in capital cost of only one per cent would effect a saving in total capital expenditure in all fields of underground drainage work of at least one million pounds per annum highlights the financial benefits which might accrue from increased knowledge.

222. We are therefore satisfied that a major research programme is required and justified and we recommend that it should be undertaken without delay.

The programme and how it should be carried out

223. We suggest that the most urgent matters to be included in the programme are as follows:—

(a) further research into the determination of loads on sewers, including vehicle loads and impact effects;

(b) investigations to verify the bedding factors in current use and the properties of bedding materials which affect these factors;

(c) research to determine the strengthening effect of concrete bed and haunch and concrete surround and the considerations which affect their strengthening properties;

(d) research in connection with the design of lines of flexible pipes;

(e) investigations into the properties of pipe materials, including particularly such matters as possible fatigue and creep effects;

(f) investigations into the criteria used for the design of sewers of rigid pipes in wide trench and embankment conditions.

224. We have considered how this programme might best be executed. Much of the immediate work must be carried out in full-scale field conditions but it

should be accompanied by parallel work in the laboratory in order to determine to what extent it is practicable truly to simulate field conditions. Any simulation that proved possible would of course be of great value in the later stages of the programme.

225. The experience we gained in our pilot programme has convinced us that a major research project of this kind could not be adequately carried out as a part-time occupation at any research establishment or University. The extensive constructional work that would be necessary would in any case make it difficult to carry out such a programme at any of the Universities, although we hope for and would seek their assistance in specific fields of some of the parallel laboratory work.

226. We consider that to execute the programme satisfactorily and to gain full value for money it will be necessary to set up, staff and equip a special full-time section at one of the Government research establishments specifically to carry out this work.

227. The section should consist of engineering and scientific staff. The precise numbers needed will become apparent during the formative period. In order to achieve a reasonable rate of progress we estimate that a total average annual expenditure of the order of £100,000 will be necessary to cover the cost of staff, equipment and constructional and experimental work. The relationship of this figure to a total annual expenditure of at least one hundred million pounds will be noted.

228. The research section could obviously be usefully employed for a very long time; and the advent of new materials and constructional techniques might well justify its permanent retention. This would be a matter to be decided in the light of the results achieved but there must be some immediate guarantee of continuity if the work is to be worthwhile. We suggest that a commitment should be made for an initial period of five years, the position to be reviewed then in the light of the progress made.

229. It will take some little time to staff and bring the section into full operation but we would urge that the officer who will take charge of it be appointed as soon as possible. There will be much detailed planning of the programme to be undertaken and it is desirable that he should take part in this work from the outset.

230. The Working Party, in association with the Director of the research establishment, should be responsible for the overall planning and execution of the programme and its co-ordination with relevant research elsewhere; and for advising on the application of the results to practical design.

The interim period

(a) Research

231. We have considered whether, whilst we await a decision on this matter, it would be reasonable for us to use the funds remaining at our disposal to institute a further limited programme of experiments, for example in connection with the strengthening effect of concrete bed and haunch and concrete surround. We have concluded that the expenditure involved would not be

justified unless a subsequent major programme could be guaranteed. A too limited programme on this subject could be misleading rather than helpful and we are convinced that research must be on the large scale we are suggesting if it is to be worthwhile.

232. However, we shall consider the possibility of instituting limited laboratory work into creep and fatigue effects in pipes of various materials. This would not become abortive even if it were not extended, and the expenditure would be justified.

(*b*) *Design methods and criteria*

233. The major research programme will take several years to complete and it is necessary that during this interim period the design of sewer pipelines shall be carried out on a safe but not extravagant basis.

234. At present we are faced with a situation in which we have inadequate evidence both in respect of rational design theories and the criteria to be used with them; and of the behaviour in present-day conditions of sewers constructed in accordance with the traditional K29 rules.

235. After careful consideration of all the information available to us, including research work and practice in the United States and Germany as well as our own pilot experiments and the Road Research Laboratory's work, we suggest that the rational design of sewers constructed with rigid pipes should be undertaken on the basis of the work of Marston, Spangler and Schlick. Detailed methods of calculation based on these theories are set out in National Building Studies Special Report No. 37, recently published by the Building Research Station (H.M.S.O. London, 1967, price 15s. 0d.). We believe that the significant difference, illustrated in the diagrams at Appendices B, C and D, between the results of design based on the simplified tables set out in Special Report No. 32 and design based on the traditional K29 rules indicates the need for more scope for the application of local judgment in assessing the loading conditions likely to be applicable to each particular sewer. Until further experimental evidence can be obtained we therefore suggest that the following criteria, which differ in some respects from those recommended in both Special Reports Nos. 32 and 37, and which give greater scope for individual assessment of loading conditions, should be used where rational design methods are applied:—

(a) for sewers laid under main traffic routes and under roads which are liable to be used for temporary diversion of heavy traffic, provision should be made for a maximum of eight wheel loads, each of 20,000 lbs. static weight, arranged as in B.S.153, Type HB road loading, acting simultaneously with an impact factor of 1·3; (see note 1)

(b) for sewers laid under other roads, except access roads used only for very light traffic, provision should be made for a maximum of two wheel loads, each of 16,000 lbs. static weight, spaced 3 ft. apart, acting simultaneously with an impact factor of 1·5; (see notes 1 and 2)

(c) for sewers laid in fields, gardens and lightly-trafficked access roads, provision should be made for a maximum of two wheel loads, each of 7,000 lbs. static weight, spaced 3 ft. apart, acting simultaneously with an impact factor of 2·0; (see note 1)

(d) the maximum distributed surcharge load (e.g. stacks of earth, bricks, paving slabs etc.) ever likely to be imposed on the ground over the pipeline should be assessed. If this is unlikely to be greater than 500 lbs./sq. ft. and 15 ft. x 15 ft. in extent in plan (and we would expect this to be sufficient to cater for most foreseeable circumstances) no separate provision need be made for it. If special circumstances apply and there is a reasonable risk of a distributed surcharge load greater in quantity or extent than that quoted above being applied, specific provision should be made for the estimated maximum load; (see note 3)

(e) the total effective design load will normally be the sum of the fill load plus the vehicle load. Where special provision has to be made for a distributed load (see (d) above) it should be assumed that the distributed load will not act simultaneously with the concentrated vehicle load. The total effective external design load will then be the sum of the fill load plus the distributed load or the sum of the fill load plus the vehicle load, whichever is the greater in the given conditions;

(f) it will be possible in some cases, by limiting the width of the trench during construction, to design on narrow trench conditions. In such instances the engineer should carefully assess the likelihood of excavation adjoining the trench, to the same depth as the sewer, being carried out at some later date before deciding whether narrow trench conditions should in fact be applied to the design. If a sewer is designed on narrow trench conditions, it is essential that the related stringent site requirements concerning trench supports are in fact observed on the site;

(g) the bedding factors recommended in National Building Studies Special Reports Nos. 32 and 37 should be adopted;

(h) no bedding correction (C_{BS}) factor should be applied. We have no evidence that such a factor may not ultimately be necessary but we consider it illogical for the present to continue to apply a refinement of this nature to a design method the accuracy of which is affected to a far greater extent by other as yet indeterminable factors;

(i) the design should be undertaken on the basis of a working strength
   (i) in the case of unreinforced pipes, of eighty per cent of the guaranteed minimum crushing strength (variously referred to in different Standard Specifications as 'minimum ultimate strength', 'safe crushing test strength' and 'crushing strength');
   (ii) in the case of reinforced concrete pipes, on the guaranteed minimum 0·01 in. crack strength (referred to in the relevant Standard Specification as the 'minimum proof test strength').

These bases will provide the safety margin between working strength and ultimate strength which we consider desirable (see note 4).

NOTES

1. The decision regarding the loading category into which a particular location falls is a matter for the engineer's judgment. However, careful note should be made of the need for additional protection of sewers designed on a particular basis in the event of it being necessary at some future date to upgrade the traffic-carrying capacity of the roads under which they are laid. We suggest that 'main traffic routes and roads liable to be used for temporary diversion of heavy traffic' might be taken as those designed in accordance with Charts I and II of Road Note No. 29 "A guide to the structural design of flexible and rigid pavements for new roads", H.M.S.O. London 1965, price 3s. 0d.

2. As the recommendation in sub-paragraph (b) is for two 16,000 lb. wheel loads in isolation, Charts C 13 and C 14 in National Building Studies Special Report No. 37 may be used for calculation purposes and footnote 2 thereto disregarded in this context. (Effective load imposed by two 16,000 lb. wheel loads 3 ft. apart = effective load shown in Charts C 13 and C 14 $\times \frac{16,000}{7,000}$.)

3. Consideration of the nature and extent of distributed surcharge loads that might be expected in practice led us to the opinion that it would be unreasonable always to make provision for a uniformly distributed load of unlimited extent in plan, as has been done up to the present. In normal circumstances it seems unlikely that a load of this type will exceed 500 lbs./sq. ft. and 15 ft. by 15 ft. in plan, and we find that the effect of such a load is not appreciably greater than the effect of the minimum vehicle load for which we are suggesting that provision should be made. Hence we are proposing that no special provision need be made for distributed loads unless they are likely to exceed in quantity or area that quoted above.

4. We have used the expression 'safety margin' in this manner in the hope of avoiding confusion which appears to have arisen in the interpretation of the expression 'factor of safety' in relation to the various ways in which pipe strengths are expressed.

236. For engineers who decide not to apply individual design from first principles to each sewer we hope shortly to arrange for the publication of what will in effect be a revision of the simplified tables of National Building Studies Special Report No. 32 based on the above criteria.

237. In respect of the traditional K29 rules it will be evident from the opinions we have expressed in paragraphs 178 to 184 that, in the context of increasing mechanisation of sewer construction, we do not in general favour the use of the natural trimmed bottom of the trench for bedding sewer pipes. In the appendix to our first interim report we advised that this form of bedding should not be used with flexible pipes and we have considered whether we should also immediately advise specific restrictions on its use with rigid pipes. Strong opposition has been expressed by some engineers and pipe manufacturers to our views on this subject and to any additional restrictions in this respect; they suggest that there is a lack of field-scale experimental evidence on which to base specific recommendations. We accept that to prove the validity of our views on this subject, which are based principally on our judgment and experience of the effect of the increasing use of modern constructional techniques, more experimental evidence is necessary. Although we believe that the disadvantages of this method of bedding will increase as modern constructional techniques are increasingly applied and skilled labour becomes even more scarce, we consider that we would not be justified at this stage in suggesting severe restrictions on its use with rigid pipes until our views can be supported or refuted by satisfactory experimental evidence. We think, however, that there is sufficient practical evidence to make it reasonable and desirable to restrict the use of this method of bedding to rigid pipes of not more than 12 in. diameter.

238. Where in-situ concrete strengthening is used, engineers should of course supplement the K29 rules by specifying the strength of concrete to be used (see paragraph 158) and the thickness of surround to be provided with larger sizes of pipe (see paragraph 168).

239. We are convinced that the use of mechanical joints with rigid sewer pipes should eventually become virtually universal (see paragraph 121). We recognise that large quantities of pipes for use with rigid joints are still being produced; and that with some materials a complete change-over to mechanically-jointed pipes may involve changes in manufacturing techniques and plant, a process that will take some time. Nevertheless, we suggest that pending the universal availability of mechanical joints users should endeavour to obtain them wherever rigid pipes are laid without concrete bed or protection (see paragraphs 151 and 184).

240. We have already made it clear that we consider that the K29 rules would require major extension to meet modern conditions if they were to be retained permanently. We are of the opinion, however, that there is no significant weight of evidence that the rules are as yet resulting in unsafe or unsatisfactory construction. Until we have sufficient information and evidence to make specific major proposals in respect of them we must therefore recommend that construction in accordance with the rules, subject to the suggestions referred to in paragraphs 237 to 239, should continue to be permitted as an alternative to rational design. We would stress, however, that those using the rules should pay particular care and attention to sewers to be laid in the extremes of the ranges they cover; it is obviously in these conditions that the smallest safety margin will occur.

241. Rational design using the revised criteria we have suggested in paragraph 235 will still result in many cases in stronger pipes or beddings with greater supporting strengths being used than design on the basis of the traditional K29 rules, even as modified by the suggestions made in paragraphs 237 to 239. The diagrams at Appendices B, C and D illustrate the differences which will result with pipes of one material of a particular strength; similar differences will occur to a greater or lesser extent with pipes of other materials and strength classes. Either the revised criteria will still result in extravagant and uneconomic design or the traditional rules provide insufficient safety margin in modern conditions. We do not know which of these statements in fact applies and without further major research we cannot find out.

242. We fully recognise that the Ministry will still be left in an illogical position as a result of these interim suggestions. This is an unsatisfactory situation but it is one which we can see no means of avoiding until a major research programme can be executed. It is not a situation which should be allowed to continue indefinitely. Engineers ought to be provided with the information they need to allow them to design and construct sewers safely and economically.

Recommendations

243. We recommend that

(i) a new research section be set up at one of the Government research establishments to carry out a major programme of experimental work in connection with the design and construction of underground pipe sewers, involving an annual expenditure of the order of £100,000 (see paragraphs 223 to 229);

(ii) the Working Party, in association with the Director of the research establishment, be responsible for the overall planning and execution of the programme and for advising on the application of the results to practical design (see paragraph 230);

(iii) until further knowledge can be gained by means of this research the Ministry be prepared to accept rational design of pipe sewers constructed with rigid pipes undertaken on the basis of the Marston theory, using the criteria suggested in paragraph 235 of this report; and that for the present the construction of sewers in accordance with the traditional Form K29 rules continue to be permitted as an alternative to rational design (see paragraph 240), subject to the use of the natural trimmed bottom of the trench being restricted to rigid pipes of not more than 12 in. diameter (see paragraph 237);

(iv) the Ministry consider making mandatory the use of mechanical joints with rigid pipes for loan sanction purposes in say 5 years time; and that in the interim period users should endeavour to obtain mechanical joints wherever rigid pipes are laid without concrete bed or protection (see paragraphs 151, 184 and 239);

(v) the dangers of indiscriminate use of design charts and tables and the desirability of individual design for most pipelines in the medium and large size ranges be noted (see paragraphs 110 and 111);

(vi) having regard to the fact that increasing shortage of skilled labour is inevitably resulting in more mechanised construction, engineers should design and specify sewer works to cater for this mechanisation in such a way that its use will result in the most economical construction whilst at the same time maintaining the high quality of workmanship and finished product that are essential (see paragraphs 192 and 193);

(vii) specifications be so written that only requirements are included that are practicable, that are expected to be attained, and that it is intended to enforce (see paragraphs 118 to 120 and 194 and 195);

(viii) a close relationship between the design office and construction in the field be regarded as essential (see paragraph 197);

(ix) having decided what pipe materials are acceptable for the scheme they are designing and having specified the bedding, class of pipe and constructional requirements for each material, engineers be encouraged to allow the contractor to tender for whichever specified combination his skill, experience, plant and labour force will allow him to construct most cheaply and efficiently (see paragraphs 198 to 201);

(x) the attention of all those concerned with design and construction be drawn to the importance of the tributary drains connected to the public sewers in the context of the drainage network as a whole; and the need to ensure that these drains are satisfactorily constructed (see paragraphs 105 and 106);

(xi) the note of guidance on practical considerations in the structural design and in the construction of small-diameter sewers and drains that we have prepared be disseminated as widely as possible amongst all those directly concerned with drainage works (see paragraphs 107 and 108);

(xii) no change be made for the present in the Ministry's Form K29 requirements in respect of sewer lines and manhole spacing, except that no objection be raised to the use of horizontal curves of reasonable radius on sewers in which men can work (see paragraphs 125 to 128) which has been accepted practice for some time but may not be well known to all users;

(xiii) particular care be taken in the design of side connections to sewers to avoid damage to the main pipeline due to the imposition of additional loads, and consequent damage to the connections themselves (see paragraphs 130 and 131);

(xiv) where sewers are constructed under roads, engineers should specify an appropriate degree of compaction of backfilling of trenches and arrange the provision of such testing facilities as are necessary to ensure compliance with the specification; and make every effort to ensure adequate temporary surface reinstatement of the trenches (see paragraphs 186 to 191).

Acknowledgements

244. Since our inception we have sought advice and help from research establishments and pipe associations, and from many local authority and consulting engineers, contractors and manufacturers. It has always been readily given and we are indebted to them for it. We shall be seeking their help again in the future and look forward to their continued co-operation.

245. We shall continue with our task whilst we await a decision on our recommendations but it will be clear that our progress will necessarily be limited until the research facilities we need can be made available to us.

We have the honour to be,
Sir,
Your obedient Servants,

Signed R. A. ELLIOTT, *Chairman*
R. R. BEAUMONT
GRANVILLE BERRY
L. H. C. EVANS
R. T. GILLET
I. H. HAINSWORTH
J. M. HASELDINE
H. P. KAUFMAN
F. G. MARTIN
J. B. STOREY
A. C. WHIFFIN
R. W. C. YEO
O. C. YOUNG

T. C. GEORGE
T. P. HUGHES
Secretaries

30th May 1967

APPENDIX A

Tests for suitability of soil material for use as bedding for sewer pipes laid underground

(a) Particle size

The maximum particle size should generally not exceed ¾ in. The presence of an occasional particle between ¾ in. and 1½ ins. is acceptable provided the total quantity of such particles is only a very small fraction of the whole. If particles over 1½ ins. are present the material should be rejected.

In cases of doubt a weighed representative sample* of material (about 5 lbs.) should be sieved†, using ¾ in. and 1½ ins. B.S. sieves. If (i) any particles are retained on the 1½ ins. sieve, or (ii) more than 5% by weight of the sample is retained on the ¾ in. sieve, the material is not acceptable, unless it is first screened so as to comply with this requirement.

(b) Ease of compaction

Apparatus required

1. Open-ended cylinder 10 ins. long and 6 ins. ± ¼ in. internal diameter (6 in. diameter pipe is suitable);
2. metal rammer with striking face 1½ ins. diameter and weighing 2 to 2½ lbs.;
3. rule.

Method

Obtain a representative sample* more than sufficient to fill the cylinder (viz. about 25 lbs.). It is important that the moisture content of the sample should not differ materially from that of the main body of material at the time of its use in the trench.

Place the cylinder on a firm flat surface and gently pour the sample material into it, *loosely and without tamping*. Strike off the top surface level with the top of the cylinder and remove all surplus material. Lift the cylinder up clear of its contents and place on a fresh area of flat surface. Place about one quarter of the material back in the cylinder and tamp vigorously until no further compaction can be obtained. Repeat with the second quarter, tamping as before, and so on for the third and fourth quarters, tamping the final surface as level as possible.

Measure down from the top of the cylinder to the surface of the compacted material. This distance in inches divided by the height of the cylinder (10 inches) is referred to as the Compaction Fraction.

Compaction Fraction	*Suitability for use*
0·1 or less	Material suitable.
0·1 to 0·3	Material suitable but requires extra care in compaction. Not suitable for flexible pipes subject to waterlogged conditions after laying.
Over 0·3	Material unsuitable.

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*To obtain a representative sample, about 1 cwt. of the proposed material should be heaped on a clean surface and divided with the spade down the middle into two halves. One of these should then be similarly divided, and so on until the required weight of sample is left.

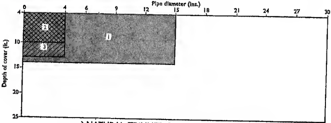
†In the sieving, clumps of material that break up under light finger pressure may be helped through the sieve, but considerable force must *not* be used to squeeze oversize clumps through the mesh.

APPENDIX B

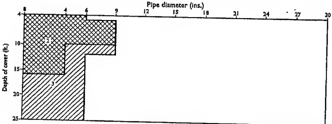
Ranges of use of standard strength unreinforced concrete pipes with various beddings using different design criteria

Sewers laid under heavily trafficked roads

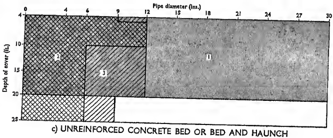
- ▩ 1 Range of use on the basis of Form K29
- ▧ 2 Range of use on the basis of Special Report No. 32
- ▨ 3 Range of use on the basis of the proposed interim rational design criteria (see paragraph 235) assuming no special provision for distributed load



a) NATURAL TRIMMED BOTTOM OF THE TRENCH



b) GRANULAR BEDDING

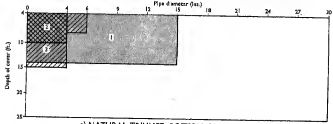


c) UNREINFORCED CONCRETE BED OR BED AND HAUNCH

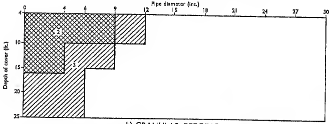
Ranges of use of standard strength unreinforced concrete pipes with various beddings using different design criteria

Sewers laid under roads other than heavily trafficked roads

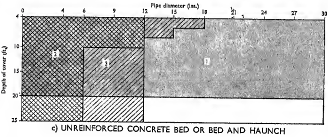
▩ 1	Range of use on the basis of Form K29
▧ 2	Range of use on the basis of Special Report No. 32
▨ 3	Range of use on the basis of the proposed interim rational design criteria (see paragraph 235) assuming no special provision for distributed load



a) NATURAL TRIMMED BOTTOM OF THE TRENCH



b) GRANULAR BEDDING



c) UNREINFORCED CONCRETE BED OR BED AND HAUNCH

APPENDIX D

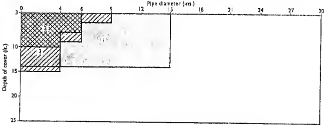
Ranges of use of standard strength unreinforced concrete pipes with various beddings using different design criteria

Sewers laid in fields and gardens

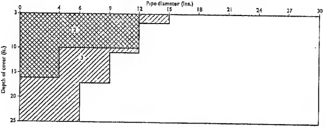
□ 1 Range of use on the basis of Form K29

▩ 2 Range of use on the basis of Special Report No. 32

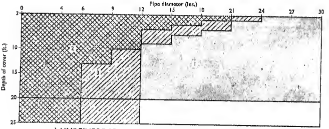
▨ 3 Range of use on the basis of the proposed interim rational design criteria (see paragraph 235) assuming no special provision for distributed load



a) NATURAL TRIMMED BOTTOM OF THE TRENCH



b) GRANULAR BEDDING



c) UNREINFORCED CONCRETE BED OR BED AND HAUNCH

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MINISTRY OF
HOUSING AND LOCAL GOVERNMENT

Working Party on the Design and Construction of Underground Pipe Sewers

Second Report

LONDON
HER MAJESTY'S STATIONERY OFFICE
1967

The Working Party on the design and construction of underground pipe sewers was appointed by the Minister of Housing and Local Government in June 1964 with the following terms of reference:—

> "to investigate the practical application of structural theory to the design and construction of buried pipe sewers having due regard to structural stability, to watertightness and to economy in capital, operational and maintenance costs; to consider and advise on the relative merits of flexible and rigid construction over a range of ground and loading conditions commonly occurring in practice; and to initiate and co-ordinate research and experiment directed towards the production of reliable design data and the co-ordination of design and construction".

Membership. The following have been members of the Working Party since its inception—

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R. R. Beaumont, Esq., M.I.C.E.
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(advised until April 1965 by N. W. B. Clarke, Esq., M.Eng., M.I.C.E.).

They were joined by
Dr. A. C. Whiffin, B.Sc., M.Sc.(Eng.), Ph.D., A.M.I.Mech.E. in April 1965;
and
L. H. C. Evans, Esq., A.M.I.C.E., A.M.I.W.E., M.R.S.H. in July 1966.

Administrative Secretary
T. C. George, Esq., M.B.E.

Technical Secretary
T. P. Hughes, Esq., A.M.I.C.E., A.M.I.Mun.E.

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